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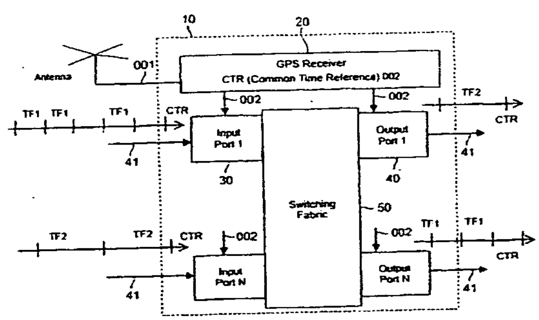

(57) Abstract: The invention describes a method for transmitting data packets over a packet switching network with widely varying link speeds. The switches of the network maintain a common time reference (CTR). Each switch along a route from a source to a destination forwards data packets in periodic time frames (TFs) of a plurality of durations that are predefined using the CTR. The time frame duration can be longer than the time duration required for transmitting a data packet, in which case the exact position of a packet in the time frame is not predetermined. In accordance with the present invention, different time frame durations: TF1, TF2, and so on are used for forwarding over links with different capacities. This invention further describes a method for transmitting and forwarding data packets over a packet switching and shared media networks. The shared media network can be of various types, including but not limited to: IEEE P1394 and Ethernet for desktop computers and room area networks, cable modem head-end (e.g., DOCSIS, IEEE 802.14), wireless base-station (e.g., IEEE 802.11), and Storage Area Network (SAN) (e.g., FC-AL, SSA). The invention further describes a method for interfacing a packet-switched network with real-time streams from various sources, such as circuit-switched telephony network sources. A data packet that is packetized at the gateway is scheduled to be forwarded to the network in a predefined time that is responsive to the common time reference. The invention relates, in particular, to timely forwarding and delivery of data packet between voice over IP (VoIP) gateways. Consequently, the invention provides a routing service between any two VoIP gateways where the end-to-end performance parameters, such as loss, delay and jitter, have deterministic guarantees. Furthermore, the invention enables gateway functions with minimum delay.

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SCHEDULING WITH DIFFERENT TIME INTERVALS

RELATED APPLICATIONS

FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

BACKGROUND OF THE INVENTION:

This invention relates to generally to a method and apparatus for transmitting of data on a communications network. More specifically, this invention relates to timely forwarding and delivery of data over the network and to their destination nodes, where the destination nodes are connected with point-to-point links or over a multiple access shared medium. Consequently, the end–to–end performance parameters, such as, loss, delay and jitter, have either deterministic or probabilistic guarantees.

The proliferation of high–speed communications links, fast processors, and affordable, multimedia–ready personal computers brings about the need for wide area networks that can carry real–time data, like telephony and video. However, the end–to–end transport requirements of real–time multimedia applications present a major challenge that cannot be solved satisfactorily by current networking technologies. Such applications as video teleconferencing, and audio and video group (many–to–many) multicasting generate data at a wide range of bit rates and require predictable, stable performance and strict limits on loss rates, end–to–end delay bounds, and delay variations ("jitter"). These characteristics and performance requirements are incompatible with the services that current circuit and packet switching networks can offer.

Circuit–switching networks, which are still the main carrier for real–time traffic, are designed for telephony service and cannot be easily enhanced to support multiple services or carry multimedia traffic. Its synchronous byte switching enables circuit–switching networks to transport data streams at constant rates with little delay or jitter. However, since circuit–switching networks allocate resources exclusively for individual connections, they suffer from low utilization under bursty traffic. Moreover, it is difficult to dynamically allocate circuits of widely different capacities, which makes it a challenge to support multimedia traffic. Finally, the synchronous byte switching of SONET, which embodies the Synchronous Digital Hierarchy (SDH), requires increasingly more precise clock synchronization as the lines speed increases [John C. Bellamy, "Digital Network Synchronization", *IEEE Communications Magazine*, April 1995, pages 70–83].

Packet switching networks like IP (Internet Protocol)–based Internet and Intranets [see, for example, A.Tannebaum, *Computer Networks* (3rd Ed) Prentice Hall, 1996] and ATM (Asynchronous Transfer Mode) [see, for example, Handel et al., *ATM Networks: Concepts, Protocols, and Applications* (2nd Ed.) Addison–Wesley, 1994] handle bursty data more efficiently than circuit switching, due to their statistical multiplexing of the packet streams. However, current packet switches and routers operate asynchronously and provide best effort service only, in which end–to–end delay and jitter are neither guaranteed nor bounded. Furthermore, statistical variations of traffic intensity often lead to congestion that results in excessive delays and loss of packets, thereby significantly reducing the fidelity of real–time streams at their points of reception.

Efforts to define advanced services for both IP and ATM have been conducted in two levels: (1) definition of service, and (2) specification of methods for providing different services to different packet streams. The former defines interfaces, data formats, and performance objectives. The latter specifies procedures for processing packets by hosts and switches/routers. The types of services that defined for ATM include constant bit rate (CBR), variable bit rate (VBR) and available bit rate (ABR).

The real–time transport protocol (RTP) [H. Schultzrinne et. al, "RTP: A Transport Protocol for Real–Time Applications", *IETF Request for Comment RFC1889*, January 1996] is a method for encapsulating time–sensitive data packets and attaching to the data time related information like time stamps and packet sequence number.

One approach to an optical network that uses synchronization was introduced in the synchronous optical hypergraph [Y. Ofek, "The Topology, Algorithms And Analysis Of A Synchronous Optical Hypergraph Architecture", Ph.D. Dissertation, Electrical Engineering Department, University of Illinois at Urbana, *Report No. UIUCDCS–R–87–1343*, May 1987], which also relates to how to integrate packet telephony using synchronization [Y. Ofek, "Integration Of Voice Communication On A Synchronous Optical Hypergraph", *IEEE INFOCOM'88*, 1988]. In the synchronous optical hypergraph, the forwarding is performed over hyper–edges, which are passive optical stars. In [Li et al., "Pseudo–Isochronous Cell Switching In ATM Networks", *IEEE INFOCOM'94*, pages 428–437, 1994; Li et al., "Time–Driven Priority: Flow Control For Real–Time Heterogeneous Internetworking", *IEEE INFOCOM'96*, 1996] the synchronous optical hypergraph idea was applied to networks with an arbitrary topology and with point–to–point links. The two papers [Li et.al., "Pseudo-Isochronous Cell Switching In ATM Networks", *IEEE INFOCOM'94*, pages 428–437, 1994; Li et al., "Time–Driven Priority: Flow Control For Real–Time Heterogeneous Internetworking", *IEEE INFOCOM'96*, 1996] provide an abstract (high level)

description of what is called "RISC–like forwarding", in which a packet is forwarded, with little if any details, one hop every time frame in a manner similar to the execution of instructions in a Reduced Instruction Set Computer (RISC) machine.

This invention also relates to generally to a method and apparatus for transmitting of data on a communications network. More specifically, this invention relates to timely forwarding and delivery of data packets over the network to Voice over Internet Protocol (**VoIP**) gateways (see for example: [M. Hamdi, O. Verscheure, J-P Hubaux, I. Dalgic, and P. Wang, *Voice Service Interworking and IP Networks*, IEEE Communications Magazine, May 1999, pp. 104-111]). Consequently, between any two VoIP gateways the end-to-end performance parameters, such as, loss, delay and jitter, have deterministic guarantees.

In U.S. Pat. No. 5,418,779, Yemini et al. discloses switched network architecture with common time reference. The time reference is used in order to determine the time in which multiplicity of nodes can transmit simultaneously over one predefined routing tree to one destination. At every time instance the multiplicity of nodes are transmitting to different single destination node.

SUMMARY OF THE INVENTION:

In accordance with the present invention, a method is disclosed providing virtual pipes that carry real–time traffic over packet switching networks with widely varying link speeds, while guaranteeing end–to–end performance. The method combines the advantages of both circuit and packet switching. It provides for allocation for the exclusive use of predefined connections and for those connections it guarantees loss free transport with low delay and jitter. When predefined connections do not use their allocated resources, other non–reserved data packets can use them without affecting the performance of the predefined connections.

Under the aforementioned prior art methods for providing packet switching services, switches and routers operate asynchronously. The present invention provides real–time services by synchronous methods that utilize a time reference that is common to the switches and end stations comprising a wide area network. The common time reference can be realized by using UTC (Coordinated Universal Time), which is globally available via, for example, GPS (Global Positioning System – see, for example: [Peter H. Dana, "Global Positioning System (GPS) Time Dissemination for Real–Time Applications", *Real–Time Systems*, 12, pp. 9–40, 1997]. By international agreement, UTC is the same all over the world. UTC is the scientific name for what is commonly called GMT (Greenwich Mean Time), the time at the 0 (root) line of longitude at Greenwich, England. In 1967, an international agreement established the length of a second as the duration of 9,192,631,770 oscillations of the cesium atom. The adoption

of the atomic second led to the coordination of clocks around the world and the establishment of UTC in 1972. The Time and Frequency Division of the National Institute of Standards and Technologies (NIST) (see http://www.boulder.nist.gov/timefreq) is responsible for coordinating UTC with the International Bureau of Weights and Measures (BIPM) in Paris.

UTC timing is readily available to individual PCs through GPS cards. For example, TrueTime, Inc.'s (Santa Rosa, California) PCI–SG provides precise time, with zero latency, to computers that have PCI extension slots. Another way by which UTC can be provided over a network is by using the Network Time Protocol (NTP) [D. Mills, "Network Time Protocol" (version 3) *IETF RFC 1305*]. However, the clock accuracy of NTP is not adequate for inter–switch coordination, on which this invention is based.

In accordance with the present invention, the synchronization requirements are independent of the physical link transmission speed, while in circuit switching the synchronization becomes more and more difficult as the link speed increases.

In accordance with the present invention, timing information is not used for routing, and therefore, in the Internet, for example, the routing is done using IP addresses or an IP tag/label.

In accordance with the present invention, timing information is provided by using a Common Time Reference (CTR) signal, one such source is the above mentioned GPS. CTR is used for the timely forwarding over links with plurality of different time frame durations: TF1, TF2, and so on. Employing different time frame durations are useful in heterogeneous networks with widely varying link speeds, as shown in the following table. That is, the number of bytes that can be transmitted during one time frame of, say, 500/125/12.5 microseconds changes according to the link capacity.

Link capacity	Number of bytes per TFs – 125 microseconds	Number of bytes per TFs – 500 microseconds	Number of bytes per TFs – 12.5 microseconds
10 Gb/s	156,250	625,000	15,625
1 Gb/s	15,625	62,500	1,562
155 Mb/s	2,420	9,680	242
45 Mb/s	703	2,812	70

In accordance with the present invention, the synchronous virtual pipes (SVPs) are accessed by end-stations that are located across a shared media network. The shared media network can be of various types: IEEE P1394 and Ethernet for desktop

computers and room area networks, cable modem head-end (e.g., DOCSIS, IEEE 802.14), wireless base-station (e.g., IEEE 802.11), and Storage Area Network (SAN) (e.g., FC-AL, SSA). The end-station can be of corresponding various types: for IEEE 1394: video cameras, VCR and video disk; for cable modem: set-top box with multiple Ethernet connections to video cameras, VCRs; for wireless: desktop computers and mobile units; and for SAN: disk drives, tape drives, RAM disks, electronic disks, and other storage devices. More specifically:

IEEE P1394 [*P1394 Standard for a High Performance Serial Bus*, IEEE P1394 Draft 8.0v4, November 21, 1995] - This standard describes a high speed, low cost serial bus suitable for use as a peripheral bus or a backup to parallel back-plane buses.

DOCSIS [*Data-Over-Cable Service Interface Specifications Radio Frequency Interface Specification*, SP-RFI-I04-980724]. The goal of this specification is to enable cable operators to deploy high-speed data communications systems on cable television systems. It provides definition, design, development and deployment of data-over-cable systems on an uniform, consistent, open, non proprietary, multi-vendor interoperable basis. The intended service will allow transparent bi-directional transfer of Internet Protocol (IP) traffic, between the cable system head-end and customer locations, over an all-coaxial or hybrid fiber/coax (HFC) cable network.

IEEE 802.14 [*IEEE 802.14/a Draft 3 Revision 2 for Cable-TV access method and physical layer specification*, 1 August, 1998], this standard is intended to provide complete support of Asynchronous Transfer Mode (ATM). This support comprises supporting the following: (1) The ATM layer service, as defined in ITU-T Recommendation I.150, (2) Transport of ATM cells across the HFC MAC, (3) The five ATM Service Categories defined in the ATM Forum Traffic Management specification, along with their associated Quality-of Service and traffic contract parameters, (4) Point-to-point and unidirectional point-to-multipoint ATM virtual connection links, (5) ATM Virtual Path (VP) and Virtual Channel (VC) links which are concatenated with other VP- and/or VC- links to form VP connections or VC connections, (6) Permanent Virtual Connections (PVCs) and Switched Virtual Connections (SVCs), including support for the ATM Forum Signaling 4.0 specification for establishing and releasing SVCs and the Integrated Layer Management Interface (formerly, Interim Layer Management Interface).

IEEE 802.11 [*Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications*, IEEE Std 802.11-1997] - the medium access control (MAC) and physical characteristics for wireless local area networks (LANs) are specified in this standard, part of a series of standards for local and metropolitan area networks. The medium access control unit in this standard is designed to support physical layer units as they may be adopted dependent on the availability of spectrum.

This standard contains three physical layer units: two radio units, both operating in the 2400-2500 MHz band, and one base-band infrared unit. One radio unit employs the frequency-hopping spread spectrum technique, and the other employs the direct sequence spread spectrum technique.

There are several variants of Storage Area Network (SAN), for example: (1) ANSI standard X3T11, FC-AL - Fiber Channel Arbitrated Loop [see, for example, Robert W. Kembel, *Arbitrated Loop*, Connectivity Solutions, 1997], and (2) ANSI standard X3T10, SSA - Serial Storage Architecture [see, for example, *Serial Storage Architecture A Technology Overview, Version 3.0,* SSA Industry Association 1995]. SAN provides connectivity for a wide variety of storage devices, such as, disk drives, tape drives, RAM disks, electronic disks, and other storage devices. The underlying network for SSA is a ring network with concurrent access and spatial bandwidth reuse [Y. Ofek, *Overview of the MetaRing Architecture*, Computer Networks and ISDN Systems, Vol. 26, Nos. 6-8, March 1994, pp. 817-830], thus, a plurality of end-stations can send data packets to this type shared media network at the same time.

Fiber Channel (FC) - ANSI X3T11, using the arbitrated loop (AL) topology (abbreviated FC-AL) as a replacement for Small Computer Storage Interface (SCSI). Serial Storage Architecture (SSA) is a standard for peripheral interconnections, bringing with it higher levels of performance, availability, fault tolerance, and connectivity at low cost. FC-AL and SSA are high performance serial interfaces designed to connect disk drives, optical drives, tape drives, CD-ROMs, printers, scanners, and other peripherals to personal computers, workstations, servers, and storage subsystems. SSA and FC-AL facilitate migration from current SCSI equipment and will accommodate implementation of future configurations, including the use of fiber-optic connections.

These and other aspects and attributes of the present invention will be discussed with reference to the following drawings and accompanying specification.

In accordance with the present invention, a method is disclosed providing virtual pipes that carry streams of real-time traffic to/from Voice over Internet Protocol (VoIP) gateways over packet switching networks with timely forwarding and delivery. Consequently, between any two VoIP gateways the performance parameters, such as, loss, delay and jitter, have deterministic guarantees. The method combines the advantages of both circuit and packet switching. It provides for allocation for the exclusive use of predefined connections and for those connections it guarantees loss free transport with low delay and jitter. When predefined connections do not use their allocated resources, other non-reserved data packets can use them without affecting the performance of the predefined connections.

These and other aspects and attributes of the present invention will be discussed with reference to the following drawings and accompanying specification.

BRIEF DESCRIPTION OF THE DRAWINGS:

FIG. 1 is a schematic block diagram of the multiple time base synchronous virtual switch of the present invention;

FIG. 2 is a timing diagram relating the common time reference (CTR) that is aligned to UTC and super–cycles, time cycles, and multiple sizes of time frames as used in the present invention;

FIG. 3 is a schematic block diagram of a synchronous virtual pipe as used in the present invention;

FIG. 4 is a timing diagram illustrating periodic scheduling and forwarding as used in the present invention;

FIG. 5A is a schematic block diagram of the link layer of a synchronous virtual pipe of the present invention;

FIG. 5B is a data word encoding table of the present invention;

FIG. 5C is a control word encoding table of the present invention;

FIG. 6A is an illustration of the structure of a data packet with header as used in the present invention;

FIG. 6B is an illustration in detail of specific fields in the header of FIG. 6A;

FIG. 7 is a schematic block diagram of an input port of the multiple time base synchronous virtual switch of the present invention;

FIG. 8 is a flow diagram illustrating the operation of the routing controller of the present invention;

FIG. 9 is a schematic block diagram of an output port of the multiple time base synchronous virtual pipe switch of the present invention;

FIG. 10 is a schematic block diagram of the scheduling controller and transmit buffer of the present invention;

FIG. 11 is a flow diagram illustrating the operation of the scheduling controller of the present invention;

FIG. 12 is a flow diagram illustrating the operation of the select buffer and time–driven preemption controller of the present invention;

FIG. 13 is a timing diagram illustrating timely periodic transmission of data packets across multiple time bases as in the present invention;

FIG. 14 is a flow diagram illustrating additional detail of the operation of the scheduling controller of the present invention;

FIG. 15 is a flow diagram illustrating additional detail of the operation of an alternate embodiment of the scheduling controller of the present invention;

FIG. 16 is a schematic block diagram of the shared media network of the present invention;

FIG. 17 is a schematic block diagram of an alternate embodiment of the shared

media network of the present invention;

FIG. 18 is a timing diagram illustrating timely periodic transmission of data across the shared media network as in the present invention;

FIG. 19 is a timing diagram illustrating timely periodic reception of data across the shared media network as in the present invention;

FIG. 20 illustrates the protocol used to schedule transmission access to the shared media network as used in the present invention;

FIG. 21 illustrates the protocol used to schedule reception access to the shared media network as used in the present invention;

FIG. 22A is an illustration of the types and organization of data contained within the request messages in one embodiment of the present invention;

FIG. 22B is an illustration of the types and organization of data contained within the schedule messages in one embodiment of the present invention;

FIG. 23 is a timing diagram illustrating the end-to-end synchronization within synchronous virtual pipe as provided by the present invention;

FIG. 24A is a schematic block diagram of an end-to-end communication utilizing the shared media network of the present invention;

FIG. 24B is a timing diagram illustrating the timely transmission of data in the communication shown in FIG. 24A;

FIG. 25A is a timing diagram illustrating the constant data rate requirements of a data stream having simple isochronous periodicity; and

FIG. 25B is a timing diagram illustrating the varying data rate requirements of a data stream having complex isochronous periodicity.

FIG. 26 is a schematic block diagram of a VoIP gateway of the present invention;

FIG. 27 is a schematic block diagram of a synchronous virtual pipe interface to a VoIP gateway as provided by the present invention;

FIG. 28 is a timing diagram illustrating processing, assembling of packets of digital samples, and on-time transmission of the data packets of the present invention;

FIG. 29 is a timing diagram illustrating the receipt, separation of samples from the packet, and other processing of packets of data of the present invention;

FIG. 30 is a timing diagram illustrating multiplexing of multiple streams or calls into one data packet in the present invention;

FIG. 31 is a timing diagram illustrating demultiplexing of data packets into multiple streams or calls in the present invention;

FIG. 32 illustrates both a schematic block diagram of an end-to-end VoIP connection and a timing diagram illustrating the timing of same schematic block diagram providing synchronized VoIP operation as in the present invention;

FIG. 33 is a schematic block diagram of time frame call multiplexing using headerless time-based routing of the present invention;

FIG. 34 is a timing diagram of the headerless time-based routing of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT:

While this invention is susceptible of embodiment in many different forms, there is shown in the drawing, and will be described herein in detail, specific embodiments thereof with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the specific embodiments illustrated.

The present invention relates to a system and method for transmitting and forwarding packets over a packet switching network. The switches of the network maintain a common time reference, which is obtained either from an external source (such as GPS—Global Positioning System) or is generated and distributed internally. The common time reference is used to define time intervals, which include time super–cycles, time cycles, time frames, time slots, and other kinds of time intervals. The time intervals are arranged both in simple periodicity and complex periodicity (like seconds and minutes of a clock).

A packet that arrives to an input port of a switch, is switched to an output port based on specific routing information in the packet's header (e.g., IPv4 destination address in the Internet, VCI/VPI labels in ATM). Each switch along a route from a source to a destination forwards packets in periodic time intervals that are predefined using the common time reference. Each link connecting switches along the route from source to destination may use identical time intervals. Alternatively, each link connecting switches along the route from source to destination may use different time intervals generated from or otherwise related to the common time reference.

A time interval duration can be longer than the time duration required for communicating a packet, in which case the exact position of a packet in the time interval is not predetermined. A packet is defined to be located within the time interval which contains the communication of the first bit of the packet, even if the length of the packet is sufficiently long to require multiple time intervals to communicate the entire packet.

Packets that are forwarded inside the network over the same route and in the same periodic time intervals constitute a virtual pipe and share the same pipe–ID. A pipe–ID can be either explicit, such as a tag or a label that is generated inside the network, or implicit such as a group of IP addresses. A virtual pipe can be used to transport data packets from multiple sources and to multiple destinations. The time interval in which a switch forwards a specific packet is determined by the packet's

pipe–ID, the time it reaches the switch, and the current value of the common time reference.

A virtual pipe provides deterministic quality of service guarantees to the packets that are travelling through it. In accordance with the present invention, congestion–free packet switching is provided for pipe–IDs in which capacity in their corresponding forwarding links and time intervals is reserved in advance. Furthermore, packets that are transferred over a virtual pipe reach their destination in predefined time intervals, which guarantees that the delay jitter or delay uncertainty is smaller than or equal to one time interval.

A system is provided for managing data transfer of data packets from a source to a destination. The transfer of the data packets is provided during a predefined time interval, comprised of a plurality of predefined time frames. The system is further comprised of a plurality of switches. A virtual pipe is comprised of at least two of the switches interconnected via communication links in a path. A common time reference signal is coupled to each of the switches, and a scheduling controller maps selected predefined time frames for transfer into and out from each of the respective switches responsive to the common time reference signal. Each communications link may use a different time frame duration generated from the common time reference signal.

Different time frame durations can be required when utilizing communications links of differing bandwidth or capacity. For example, common communications links today include slow links, such as DS1 or T1 that are inherently limited to about 1.5 Mbit/s of bandwidth, and faster links, such as an OC–3 channel that has 155 Mbit/s of bandwidth. A time frame suitable for a T1 link may prove to be interminably long for an OC–3 link. Similarly, a time frame duration suitable for an OC–3 link may be too short to be useful on a T1 link. Similar circumstances arise with any two or more communications links of different capacity (e.g., DS0, T1, T3, OC–3, OC–12, and OC–48).

In general, a slower link speed suggests a longer time frame duration, and a faster link speed suggests a shorter time frame duration, but the time frame duration does not need to be adjusted to meet these suggestions. Any number of links having different capacities may share the same time frame duration. Conversely, different time frame durations could be selected for various ones of a plurality of links all having the same identical bandwidth. The present invention is directed to the case where the time frame durations are different on at least two of the communications links, irrespective of the capacity or available bandwidth of those links.

For each switch, there is a first predefined time frame within which a respective data packet is transferred into the respective switch, and a second predefined time frame within which the respective data packet is forwarded out of the respective switch, wherein

the first and second predefined time frames may have different durations. The time assignment provides consistent fixed intervals between the time between the input to and output from the virtual pipe.

In a preferred embodiment, there is a predefined subset of the predefined time frames during which the data packets are transferred in the switch, and for each of the respective switches, there are a predefined subset of the predefined time frames during which the data packets are transferred out of the switch.

Each of the switches is comprised of one or a plurality of addressable input and output ports. A routing controller maps each of the data packets that arrives at each one of the input ports of the respective switch to a respective one or more of the output ports of the respective switch.

For each of the data packets, there is an associated time of arrival to a respective one of the input ports. The time of arrival is associated with a particular one of the predefined time frames. For each of the mappings by the routing controller, there is an associated mapping by a scheduling controller, which maps of each of the data packets between the time of arrival and forwarding time out. The forwarding time out is associated with a specified predefined time frame.

In the preferred embodiment, there are a plurality of the virtual pipes comprised of at least two of the switches interconnected via communication links in a path. The communication link is a connection between two adjacent switches; and each of the communications links can be used simultaneously by at least two of the virtual pipes. Multiple data packets can be transferred utilizing at least two of the virtual pipes.

In some configurations of this invention there is a fixed time difference, which is constant for all switches, between the time frames for the associated time of arrival and forwarding time out for each of the data packets. The fixed time difference is a variable time difference for some of the switches. A predefined interval is comprised of a fixed number of contiguous time frames comprising a time cycle. Data packets that are forwarded over a given virtual pipe are forwarded from an output port within a predefined subset of time frames in each time cycle. Furthermore, the number of data packets that can be forwarded in each of the predefined subset of time frames for a given virtual pipe is also predefined.

In some other configurations of this invention a virtual pipe can be constructed of communication links each with different time frame and/or time cycle duration. Furthermore, a communication link can be used by plurality of pipes each with different time frame duration and/or different time cycle duration.

The time frames associated with a particular one of the switches within the virtual pipe are associated with the same switch for all the time cycles, and are also associated with one of input into or output to or from the particular respective switch. Note that

each input or output port can be associated with different time frame duration and/or different time cycle interval.

In a more general construction of the present invention, a time cycle can be constructed of a reoccurring sequence of time frames, where each time frame can have different time duration. In this case, the time frame duration depends on the time frame position within the time cycle. This implies that two consecutive time frames within the same time cycle can have different time frame durations.

In some configurations of this invention there is a constant fixed time between the input into and output from a respective one of the switches. This fixed time can measured by using either the time frame duration on the input link or the time frame duration on the output link. Furthermore, this fixed time is reoccurring within each of the time cycles. A fixed number of contiguous time cycles comprise a super cycle, which is periodic. Data packets that are forwarded over a given communications link are forwarded from an output port within a predefined subset of time frames in each super cycle. Furthermore, the number of data packets that can be forwarded in each of the predefined subset of time frames within a super cycle for a given communications link is also predefined.

In the preferred embodiment the common time reference signal is coupled from a GPS (Global Positioning System), and is in accordance with the UTC (Coordinated Universal Time) standard. The UTC time signal does not have to be received directly from GPS. Such signal can be received by a switch by using various means, as long as the delay or time uncertainty associated with that UTC time signal does not exceed half of the shortest time frame duration that is associated with that switch.

In one embodiment, the super cycle duration is equal to one second as measured using the UTC (Coordinated Universal Time) standard. In an alternate embodiment the super cycle duration spans multiple UTC seconds. In another alternate embodiment the super cycle duration is a fraction of a UTC second. In the most preferred embodiment, the super–cycle duration is a small integer number of UTC seconds.

The communication links can be of fiber optic, copper, and wireless communication links for example, between a ground station and a satellite, and between two satellites orbiting the earth. The communication link between two nodes does not have to be a serial communication link. A parallel communication link can be used – such link can simultaneously carry multiple data bits, associated clock signal, and associated control signals.

The data packets can be Internet protocol (IP) data packets, and asynchronous transfer mode (ATM) cells, and can be forwarded over the same virtual pipe having an associated pipe identification (PID). The PID can be an Internet protocol (IP) address, Internet protocol group multicast address, an asynchronous transfer mode (ATM), a

virtual circuit identifier (VCI), and a virtual path identifier (VPI), or (used in combination as VCI/VPI).

The routing controller determines three possible associations of an incoming data packet: (1) the output port, (2) the link type, characterized by the time frame, time cycle and super cycle durations that are associated with it, and (3) the time of arrival (ToA). The ToA is then used by the scheduling controller for determining when a data packet should be forwarded by the select buffer and time–driven preemption controller to the next switch in the virtual pipe. The routing controller utilizes at least one of Internet protocol version 4 (IPv4), Internet protocol version 6 (IPv6) addresses, Internet protocol group multicast address, Internet MPLS (multi protocol label swapping or tag switching) labels, ATM virtual circuit identifier and virtual path identifier (VCI/VPI), and IEEE 802 MAC (media access control) addresses, for mapping from an input port to an output port.

Each of the data packets is comprised of a header, which includes an associated time stamp. For each of the mappings by the routing controller, there is an associated mapping by the scheduling controller, of each of the data packets between the respective associated time–stamp and an associated forwarding time out, which is associated with one of the predefined time frames. The time stamp can record the time in which a packet was created by its application.

In one embodiment the time stamp is generated by an Internet real–time protocol (RTP), and by a predefined one of the sources or switches. The time stamp can be used by a scheduling controller in order to determine the forwarding time of a data packet from an output port.

Each of the data packets originates from an end station, and the time stamp is generated at the respective end station for inclusion in the respective originated data packet. Such generation of a time stamp can be derived from UTC either by receiving it directly from GPS or by using the Internet's Network Time Protocol (NTP). Alternatively, the time stamp can be generated at a sub–network boundary or at the boundary of the synchronous virtual pipe.

In accordance with the present invention, a system is provided for transferring data packets across a data network while maintaining for reserved data traffic constant bounded jitter (or delay uncertainty) and no congestion–induced loss of data packets. Such properties are essential for many multimedia applications, such as, telephony and video teleconferencing.

In accordance with the design, method, and illustrated implementation of the present invention, one or a plurality of virtual pipes **25** are provided, as shown in FIG. 3, over a data network with general topology. Such data network can span the globe. Each virtual pipe **25** is constructed over one or more switches **10**, shown in FIG. 3, which are

interconnected via communication links **41** in a path.

FIG. 3 illustrates a virtual pipe **25** from switch **A**, through switches **B** and **C**, and ending at switch **D**. The virtual pipe **25** transfers data packets from at least one source to at least one destination. As shown, switch **A** may accept data from a plurality of sources via communications links **41**. Also as shown, switch **D** may output data to a plurality of destinations via communications links **41**.

The data packet transfers over the virtual pipe **25** via switches **10** are designed to occur during a plurality of predefined time intervals, wherein each of the predefined time intervals is comprised of a plurality of predefined time frames. The timely transfers of data packets are achieved by coupling a common time reference signal (not shown) to each of the switches **10**.

FIG. 1 is a schematic block diagram of the multiple frame duration synchronous virtual pipe (SVP) switch **10** of the present invention. The SVP switch **10** comprises a common time reference means **20**, at least one input port **30**, at least one output port **40**, and a switching fabric **50**. In the preferred embodiment, the common time reference means **20** is a GPS receiver that receives a source of common time reference **001** (e.g., UTC via GPS) via an antenna as illustrated. The common time reference means **20** provides a common time reference signal **002** to all input ports **30** and all output ports **40**. GPS time receivers are available from variety of manufacturers, such as, TrueTime, Inc. (Santa Rosa, CA). With such equipment, it is possible to maintain a local clock with accuracy of ±1 microsecond from the UTC (Coordinated Universal Time) standard everywhere around the globe.

Each respective one of the input ports **30** is coupled to the switching fabric **50**. Each respective one of the output ports **40** is coupled to the switching fabric **50**.

The SVP switch **10** of FIG. 1 is also coupled to one or more communications links **41** by way of input and output ports **30** and **40**, respectively. The communications links **41** can be implemented within an IP network.

In the present invention, the communications links **41** need not share the same time frame duration. Each of the communications links **41** may have a time frame of a different duration. As illustrated in FIG. 1, some of the communications links have a time frame duration of **TF1**, and some others of the communications links have a time frame duration of **TF2**. The present invention is not limited to two different time frame durations. Any number of different time frame durations may be accommodated by the multiple frame duration SVP switch of the present invention.

FIG. 2 is a timing diagram relating the common time reference (CTR) that is aligned to UTC and super–cycles, time cycles, and multiple sizes of time frames as used in the present invention. The top horizontal axis details the timing of a communications link employing a first time frame duration. The bottom horizontal axis details the timing

of a communications link employing a second time frame duration. Both axes are plotted with respect to the same common time reference.

As shown in FIG. 2, the communications link employing the first time frame duration comprises 80 time cycles within each super–cycle, with the time cycles numbered 0 through 79. Within each of the time cycles are 100 time frames of duration **TF1**, numbered 1 through 100. The duration of the time frame **TF1** is selected to be 125 microseconds, thus determining a time cycle to be 12.5 milliseconds and a super–cycle of exactly one UTC second.

As shown in FIG. 2, the communications link employing the second time frame duration comprises 80 time cycles within each super–cycle, with the time cycles numbered 0 through 79. Within each of the time cycles are 25 time frames of duration **TF2**, numbered from 1 through 25. The duration of the time frame **TF2** is selected to be 500 microseconds, thus determining a time cycle to be 12.5 milliseconds and a super–cycle of exactly one UTC second.

For scheduling of data transfer between two communications links, it is obviously most convenient if they share the same time frame duration. If they have different time frame durations, it is convenient to pick those durations and numbers of time frames per time cycle so that they share the same time cycle duration and super–cycle duration (as in the example shown in FIG. 2). If two communications links have different time frame durations and different time cycle durations, the respective durations and numbers of time frames and time cycles within a super–cycle should be selected to permit both communications links to share the same overall super–cycle duration.

FIG. 2 also illustrates how the common time reference signal can be aligned with the UTC (Coordinated Universal Time) standard. In this illustrated example, the duration of every super–cycle is exactly one second as measured by the UTC standard. Moreover, as shown in FIG. 2 the beginning of each super–cycle coincides with the beginning of a UTC second. Consequently, when leap seconds are inserted or deleted for UTC corrections (due to changes in the earth rotation period) the cycle and super–cycle periodic scheduling will not be affected. The time frames, time cycles, and super–cycles are associated in the same manner with all respective switches within the virtual pipe at all times.

In the embodiment illustrated in FIG. 2, the super–cycle duration is equal to one second as measured using the UTC (Coordinated Universal Time) standard. In an alternate embodiment the super–cycle duration spans multiple UTC seconds. In another alternate embodiment the super–cycle duration is a fraction of a UTC second. In the most preferred embodiment, the super–cycle duration is a small integer number of UTC seconds.

Pipeline forwarding relates to data packets being forwarded across a virtual pipe **25** with a predefined delay in every stage (either across a communication link **41** or across a switch **10** from input port **30** to output port **40**). Data packets enter a virtual pipe **25** from one or more sources and are forwarded to one or more destinations.

Referring to FIG. 3, the timely pipeline forwarding of data packets over the virtual pipe **25** is illustrated. In this example, time cycles each uniformly contain 10 time frames, and for clarity the super–cycles are not shown. A data packet is received by one of the input ports **30** of switch **A** at time frame 1, and is forwarded along this virtual pipe **25** in the following manner: (i) the data packet **41A** is forwarded from the output port **40** of switch **A** at time frame 2 of time cycle 1, (ii) the data packet **41B** is forwarded from the output port **40** of switch B, after 18 time frames, at time frame **10** of time cycle 2, (iii) the data packet **41C** is forwarded from the output port **40** of switch C, after 42 time frames, at time frame 2 of time cycle 7, and (iv) the data packet **41D** is forwarded from the output port **40** of switch **D**, after 19 time frames, at time frame 1 of time cycle 9.

As illustrated in FIG. 3,

- All data packets enter the virtual pipe **25** (i.e., forwarded out of the output port **40** of switch A) periodically at the second time frame of a time cycle, are output from this virtual pipe **25** (i.e., are forwarded out of the output port **40** of switch D) after 79 time frames.
- The data packets that enter the virtual pipe **25** (i.e., forwarded out of the output port **40** of switch **A**) can come from one or more sources and can reach switch A over one or more input links **41**.
- The data packets that exit the virtual pipe **25** (i.e., forwarded out of the output port **40** of switch **D**) can be forwarded over plurality of output links **41** to one of plurality of destinations.
- The data packets that exit the virtual pipe **25** (i.e., forwarded out of the output port **40** of switch **D**) can be forwarded simultaneously to multiple destinations, (i.e., multi–cast (one–to–many) data packet forwarding).
- The communication link **41** between two adjacent ones of the switches **10** can be used simultaneously by at least two of the virtual pipes.
- A plurality of virtual pipes can multiplex (i.e., mix their traffic) over the same communication links.
- A plurality of virtual pipes can multiplex (i.e., mix their traffic) during the same time frames and in an arbitrary manner.
- The same time frame can be used by multiple data packets from one or more virtual pipes.

For each virtual pipe there are predefined time frames within which respective data packets are transferred into its respective switches, and separate predefined time

frames within which the respective data packets are transferred out of its respective switches. Though the time frames of each virtual pipe on each of its switches can be assigned in an arbitrary manner along the common time reference, it is convenient and practical to assign time frames in a periodic manner in time cycles and super–cycles.

The switch **10** structure, as shown in FIG. 1, can also be referred to as a pipeline switch, since it enables a network comprised of such switches to operate as a large distributed pipeline structure, as it is commonly found inside digital systems and computer architectures.

FIG. 4 illustrates the mapping of the time frames into and out of a node on a virtual pipe, wherein the mapping repeats itself in every time cycle illustrating the time in, which is the time of arrival (ToA), versus the time out, which is the forwarding time out of the output port. FIG. 4 thereby illustrates the periodic scheduling and forwarding timing of a switch of a virtual pipe wherein there are a predefined subset of time frames (i, 75, and 80) of every time cycle, during which data packets are transferred into that switch, and wherein for that virtual pipe there are a predefined subset time frames (i+3, 1, and 3) of every time cycle, during which the data packets are transferred out of that switch.

In the illustrated example of FIG. 4, a first data packet **5a** arriving at the input port of the switch at time frame i is forwarded out of the output port of the switch at time frame $i+3$. In this example the data packet is forwarded out of the output port at a later time frame within the same time cycle in which it arrived. The delay in transiting the switch, *dts*, determines a lower bound on the value ($i+dts$). In the illustrated example, *dts* must be less than or equal to 3.

Also as shown in FIG. 4, a second data packet **5b** arriving at the input port of the switch at time frame 75 is forwarded out of the output port of the switch at time frame 1 within the next time cycle. In this example the data packet is forwarded out of the output port at a earlier numbered time frame but within the next time cycle from which it arrived. Note that data packets in transit may cross time cycle boundaries.

If—for example—each of the three data packets has 125 bytes (i.e. 1000 bits), and there are 80 time frames of 125 microseconds in each time cycle (i.e. a time cycle duration of 10 milliseconds), then the bandwidth allocated to this virtual pipe is 300,000 bits per second. In general, the bandwidth or capacity allocated for a virtual pipe is computed by dividing the number of bits transferred during each of the time cycles by the time cycle duration. In the case of a bandwidth in a super–cycle, the bandwidth allocated to a virtual pipe is computed by dividing the number of bits transferred during each of the super–cycles by the super–cycle duration.

Each switch **10** is comprised of a plurality of addressable input ports **30** and output ports **40**. As illustrated in FIG. 7, the input port **30** is further comprised of a

routing controller **35B** for mapping each of the data packets that arrives at each one of the input ports to a respective one of the queue to the output ports. As illustrated in FIG. 9, the output port **40** is further comprised of a scheduling controller and transmit buffer **45**.

An output port **40** is connected to a next input port **30** via a communication link **41**, as shown in FIGS. 3 and 5A. The communication link can be realized using various technologies compatible with the present invention including fiber optic conduits, copper and other wired conductors, and wireless communication links—including but not limited to, for example, radio frequency (RF) between two ground stations, a ground station and a satellite, and between two satellites orbiting the earth, microwave links, infrared (IR) links, optical communications lasers. The communication link does not have to be a serial communication link. A parallel communication link can be used—such a parallel link can simultaneously carry multiple data bits, associated clock signals, and associated control signals.

As shown in FIG. 1, the common time reference **002** is provided to the input ports **30** and output ports **40** (comprising the input/output ports **30/40**) from the GPS time receiver **20**, which receives its timing signal from the GPS antenna **001**. GPS time receivers are available from variety of manufacturers, such as, TrueTime, Inc. (Santa Rosa, CA). With such equipment, it is possible to maintain a local clock with accuracy of ±1 microsecond from the UTC (Coordinated Universal Time) standard everywhere around the globe.

FIG. 5A is an illustration of a serial transmitter and a serial receiver. FIG. 5B is a table illustrating the 4B/5B encoding scheme for data, and FIG. 5C is a table illustrating the 4B/5B encoding scheme for control signals.

Referring to FIG. 5A, a serial transmitter **49** and serial receiver **31** are illustrated as coupled to each link **41**. A variety of encoding schemes can be used for a serial line link **41** in the context of this invention, such as, SONET/SDH, 8B/10B Fiber Channel, and 4B/5B Fiber Distributed Data Interface (FDDI). In addition to the encoding and decoding of the data transmitted over the serial link, the serial transmitter/receiver (**49** and **31**) sends/receives control words for a variety of in–band control purposes, mostly unrelated to the present invention description.

However, one control word, time frame delimiter (TFD), is used in accordance with the present invention. The TFD marks the boundary between two successive time frames and is sent by a serial transmitter **49** when a CTR **002** clock tick occurs in a way that is described hereafter as part of the output port operation.

It is necessary to distinguish in an unambiguous manner between the data words, which carry the information, and the control signal or words (e.g., the TFD is a control signal) over the serial link **41**. There are many ways to do this. One way is to use the

known 4B/5B encoding scheme (used in FDDI). In this scheme, every 8–bit character is divided into two 4–bit parts and then each part is encoded into a 5–bit codeword that is transmitted over the serial link **41**.

In a preferred embodiment the serial transmitter **49** and receiver **31** comprise AM7968 and AM7969 chip sets, respectively, both manufactured by AND Corporation.

FIG. 5B illustrates an encoding table from 4–bit data to 5–bit serial codeword. The 4B/5B is a redundant encoding scheme, which means that there are more codeword than data words. Consequently, some of the unused or redundant serial codeword can be used to convey control information.

FIG. 5C is a table with 15 possible encoded control codeword, which can be used for transferring the time frame delimiter (TFD) over a serial link. The TFD transfer is completely transparent to the data transfer, and therefore, it can be sent in the middle of the data packet transmission in a non–destructive manner.

When the communication links **41** are SONET/SDH, the time frame delimiter cannot be embedded as redundant serial codeword, since SONET/SDH serial encoding is based on scrambling with no redundancy. Consequently, the TFD is implemented using the SONET/SDH frame control fields: transport overhead (TOH) and path overhead (POH). Note that although SONET/SDH uses a 125 microseconds frame, it cannot be used directly in accordance with the present invention, at the moment, since SONET/SDH frames are not globally aligned and are also not aligned to UTC. However, if SONET/SDH frames are globally aligned, SONET/SDH can be used compatibly with the present invention.

FIG. 7 is a schematic block diagram of an input port with a routing controller. As shown in FIG. 7, the input port **30** has several parts including: serial receiver 31, a routing controller 35 and separate queues to the output ports 36. The serial receiver 31 transfers the incoming data packets and the time frame delimiters to the routing controller **35**.

The controller **35** comprises a routing controller **35B** that is constructed of a central processing unit (CPU), a random access memory (RAM) for storing the data packet, read only memory (ROM) for storing the routing controller processing program; and a routing table **35D** that is used for determining the output port that the incoming data packet should be switched to.

Referring simultaneously to both FIGS. 17 and 19, FIG. 19 illustrates the timing associated with the reception data packets of the present invention. The shared media access time manager **100** is responsive to receipt of data packets from a synchronous virtual pipe **41** via an input port **30**. The data packets are transmitted to arrive **1c** at the access time manager **100** regularly at predefined time frames in each time cycle, which is just after time frame 2 in the illustrated example.

The access time manager **100** is responsible for scheduling data packets arriving from the synchronous virtual pipe **41** via the input port **30** to be transmitted via the shared media network **200** to arrive at the shared media network end-stations **300** during particular time frames within a time cycle. The data packets are transmitted at time **1d** to arrive at the end-station.

The access time manager **100** reserves time frames and schedules itself to continue to transmit data packets starting at the same time frame within each time cycle. After each additional data packet **2c**, **3c**, is received by the access time manager **100**, it is transmitted **2d**, **3d** to the appropriate end-station **300** via the shared media network **200** at a consistent scheduled respective time frame.

The regularity of arriving data at the same time frame of each time cycle provides for uninterrupted receipt of digital data at the end-stations **300**. The jitter present in the received data packet arrival times is controlled by the common time reference to be small and well-bounded. In another embodiment of this invention, a data packet that arrives at the shared media network can be scheduled to be forwarded to multiple end-station either simultaneously at the same schedule or at multiple schedules.

The SMATM has a sub-component for processing a plurality of format types of data packets **100A**. This sub-component converts from a first format types of data packets to a second format types of data packets. The first and second format types can be one of: ATM, IP, fiber channel for FC-AL, SSA, DOCSIS, IEEE 802.14, and IEEE 802.11. This sub-component **100A** is also capable of converting format types of data packets of different sizes, thus the number of transmission schedules over the shared media network can be different than the number of transmission schedules over the point-to-point network in the synchronous virtual pipe (SVP). More specifically, if within a time cycle and a super cycle there are: (1) a first number of schedules for the transmission of data packets of the first format type and (2) a second number of schedules for the transmission of data packets of the second format type; then the sub-component **100A** by means of a predefined scheduling table converts: (1) the first number of schedules to the second number of schedules and (2) the second number of schedules to the first number of schedules.

The SMATM has a sub-component **100B** for regulating the data packet flow to and from the shared media network by using a scheduling controller and transmit buffer **100B**; this component is implemented as previously described component **45** in FIG. 10. The sub-component **100B** uses four parameters: (1) the pipe-ID (PID), (2) the time stamp in the data packet header, (3) the common time reference, and (4) the time of arrival (TOA) attached by the SMATM to the incoming data packets from the shared media network and from SVP. Using these parameters sub-component **100B** assigns selected predefined time frames for synchronously transmitting data packets over the

synchronous virtual pipe and the shared media network.

Referring simultaneously to both FIGS. 17 and 20, FIG. 20 shows the protocol used to set up a schedule of periodic transmissions from an end-station **300** to the access time manager **100** for subsequent forwarding a synchronous virtual pipe **41** in the preferred embodiment of the present invention. The end-station **300** that operates as an access time responder issues a request **1a** to the access time manager **100**. The request **1a** describes the nature of the data to be transmitted and the destination, permitting the access time manager **100** to determine what parameters (e.g., periodicity, reserved time frames, etc.) needs to be scheduled to fulfill the request.

Upon determining a schedule suitable to satisfy request **1a**, the access time manager issues a response **2b** to the access time responder which describes to the corresponding end-station the parameters (e.g., periodicity, reserved time frames, etc.) have been reserved for its use. These parameters are issued with respect to a common time reference (CTR) **002** shared by all end-stations **300** and the access time manager **100** via the shared media network **200**.

Note that in one embodiment the request **1a** and the response **2b** may occur during a time interval scheduled by the access time manager specifically for use in negotiating requests. In an alternate embodiment, either or both of request **1a** and response **2b** may occur during other times such as permitted by the existing schedules maintained by the access time manager **100** for shared media network **200**.

Upon receipt of the response **2b**, the end-station access time responder is then permitted to transmit, at the indicated intervals, data packets to be forwarded to a synchronous virtual pipe. In the illustrated example, the access time responder has been scheduled to transmit data packets on the shared media network **200** at times 1c, 2c, 3c, and 4c. The access time manager **100** accepts data packets from the shared media network **200**, and then forwards corresponding data packets via the synchronous virtual pipe **41** at times **1d**, **2d**, **3d**, and **4d**, respectively. The times **1c**, **2c**, **3c**, **4c**, **1d**, **2d**, **3d**, and **4d** are all defined with respect to the common time reference signal. In another embodiment of this invention, the access time manager **100** accepts data packets in multiple parts (e.g., some cable modem protocols) from the shared media network **200**, assembles the multiple parts into data packets, and performs any other processing necessary for the request, and then forwards corresponding data packets via the synchronous virtual pipe **41**.

In another embodiment of this invention, there are two distinct data packet formats: one over SVP (e.g., IP), and the other over the shared media network. The data packet formats over the shared media networks correspond to the specific shared media protocol. In such cases, the access time manager additionally performs the necessary data packet format conversion.

In a preferred embodiment, the access time manager **100** provides a response **2b** that describes an isochronous channel on the shared media network **200**. An isochronous channel is one that provides for periodic reserved transmission of data on a shared media. The isochronous periodicity may be simple or complex. Simple isochronous periodicity provides for consistent, regular transmissions of same-sized groups of data. Complex isochronous periodicity permits irregular but defined transmissions of more than one differently sized groups of data at some regular interval.

FIG. 25A is an illustration of the data requirements for simple isochronous periodicity. In this illustrated example, data is provided in a single fixed amount at a periodic interval. Referring back to FIG. 20, in the example of FIG. 25A the access time manager **100** would schedule simple isochronous periodic transmissions at times **1c**, **2c**, **3c**, and **4c** to be of fixed and equal duration, and thus fixed and equal amounts of data for each transmission.

FIG. 25B is an illustration of the data requirements for complex or irregular isochronous periodicity. In this illustrated example, data is provided in two different amounts at a periodic interval, corresponding to a repeating pattern of I-frames and P-frames. The data requirements as shown are very common for compressed video data sources. As shown in this example, the pattern of one I-frame and several P-frames repeats once per super-cycle, although in practice the pattern may repeat at a different interval. The amount of data required for an I-frame is significantly higher than the amount of data required for each of the P-frames. As a result, this data transmission pattern has complex isochronous periodicity, requiring above-average amounts of data at some intervals (i.e., the I-frame in each super-cycle) and average amounts of data at more frequent intervals (i.e., the plurality of P-frames in each super-cycle). Referring back to FIG. 20, in the example of FIG. 25B the access time manager **100** would schedule complex isochronous periodic transmissions such that the transmission time allocated on the shared media network **200** at time **1c** would be greater than the transmission time allocated on the shared media network at times **2c**, **3c**, and **4c**.

The following is a simple numerical example for complex periodicity scheduling with compressed video sources, such as MPEG (familiarity with which is assumed below), in the following way:

Let the video-frame rate be 20 video frames per second or every 50 ms

Let Tf be 1 ms

Let k=50 and the time cycle be 50 ms

Let the size of each I video-frame be bounded by 100KBytes and the size of the P video-frames be bounded by 10KBytes.

Assume that an I video-frame is followed by five P video-frames.

Next, create a super-cycle of 6 time cycles, each time cycle has 50 time frames.

The complex periodicity forwarding can be done in the following manner:

Step 1: The video stream is divided into 2Kbytes data packets.

Step 2: The I video-frame is divided into 50 packets which are sent in 50 predefined time frames in time cycle number one.

Step 3: Each of the P video-frames is sent in 5 predefined time frames in each of the following 5 time cycles.

Step 4: GOTO Step 1 and repeat the six time cycles pattern.

In another preferred embodiment, the access time manager **100** provides in addition to the schedule message response **2b** specific TICK signals, **1t, 2t, 3t, 4t,** in FIG. 20, indicating the specific transmission time by the end-station (on access time responder). Consequently, the transmission **1c, 2c, 3c,** and **4d** are in response to TICK signals **1t, 2t, 3t,** and **4t,** respectively, as shown in FIG. 20. In such an embodiment, the isochronous channel across the shared media network **200** is actually created by the access time manager **100**. Again, the isochronous channel is one that provides for periodic reserved transmission of data on a shared media network with either simple or complex periodicity.

Referring simultaneously to both FIGS. 17 and 21, FIG. 21 shows the protocol used to set up a schedule of periodic transmissions from a synchronous virtual pipe **41** to an end-station **300** via the access time manager **100** in the preferred embodiment of the present invention. The end-station **300** that operates as an access time responder issues a request **1g** to the access time manager **100**. The request **1g** describes the nature of the data to be received and the source, permitting the access time manager **100** to determine what parameters (e.g., periodicity, reserved time frames, etc.) needs to be scheduled to fulfill the request.

Upon determining a schedule suitable to satisfy request **1g**, the access time manager issues a response **2h** to the access time responder which describes to the corresponding end-station the parameters (e.g., periodicity, reserved time frames, etc.) have been reserved for the respective source. These parameters are issued with respect to a common time reference (CTR) **002** shared by all end-stations **300** and the access time manager **100** via the shared media network **200**.

Note that in one embodiment the request **1g** and the response **2h** may occur during a time interval scheduled by the access time manager specifically for use in negotiating requests. In an alternate embodiment, either or both of request **1g** and response **2h** may occur during other times such as permitted by the existing schedules maintained by the access time manager **100** for shared media network **200**.

Upon receipt of the response **2h**, the end-station access time responder is then responsive to receive, at the indicated intervals, data forwarded from the synchronous virtual pipe **41** via the access time manager **100**. In the illustrated example, the access

time responder has been scheduled to receive data on the shared media network **200** at times **1f**, **2f**, **3f**, and **4f**. The access time manager **100** accepts data packets from the synchronous virtual pipe **41** at times **1e**, **2e**, **3e**, and **4e**, separates the data from those accepted data packets and/or performs any other processing as necessary to support the request, and forwards the corresponding data via the shared media network **200** to the end-station access time responder at times **1f**, **2f**, **3f**, and **4f**, respectively. The times 1e, **2e**, **3e**, **4e**, **1f**, **2f**, **3f**, and **4f** are all defined with respect to the common time reference signal.

In a preferred embodiment, the access time manager **100** provides a response **2h** that describes an isochronous channel on the shared media network **200**. An isochronous channel is one that provides for periodic reserved transmission of data on a shared media. The isochronous periodicity may be simple or complex.

Referring again to FIG. 25A with respect to FIG. 20, in the example of FIG. 25A the access time manager **100** would schedule simple isochronous periodic transmissions at times **1f**, **2f**, **3f**, and **4f** to be of fixed and equal duration, and thus fixed and equal amounts of data for each transmission.

Referring again to FIG. 25B with respect to FIG. 20, in the example of FIG. 25B the access time manager **100** would schedule complex isochronous periodic transmissions such that the transmission time allocated on the shared media network **200** at time **1f** would be greater than the transmission time allocated on the shared media network at times **2f**, **3f**, and **4f**.

FIG. 22A is an illustration of the types and organization of data contained within the request messages in one embodiment of the present invention. Specifically, it illustrates the format of the requests **1a** of FIG. 20 and **1g** of FIG. 21. The example request as shown contains fields indicating sender identification, device identification, device type, resource description, and request description. The sender identification may be used to identify which of the plurality of end-stations **300** is making the request. The device identification may be used to provide sub-addressing within the access time responder, thus supporting a plurality of co-located devices at the selected end-station. The device type and request description provide further information about the source and/or destination, and the requested schedule of data transfer, including but not limited to the total duration of the transfer, the total size of the transfer, the permitted granularity of the transfer, an indication of whether the data is expected to be bursty in nature, the peak, average, and lowest data rate requirements, the periodicity of the data, and an indication if extended request information is supplied. Extended request information may be used to further detail and describe the requested data transfer beyond the fields indicated in FIG. 22A.

FIG. 22B is an illustration of the types and organization of data contained within

the schedule messages in one embodiment of the present invention. Specifically, it illustrates the format of the schedule responses **2b** of FIG. 20 and **2h** of FIG. 21. The example request as shown contains fields indicating sender identification, device identification, device type, and schedule description. The sender identification, device identification, and device type parallel the corresponding entries in the requests **1a** and **1g**, respectively, as described above. The schedule description includes, but is not limited to, detailed information regarding the time frames and transmission durations that have been reserved to support the request made by the access time responder. The transmission durations may be referenced in terms of bytes transferred. Alternatively, the transmission durations may be referenced in terms of time frames, fractions of time frames, absolute time duration, and so forth. In any alternative, the information contained in the schedule message as shown in FIG. 22B provides information to the access time responder as to which time intervals are available in the shared media network **200** for its exclusive use to support the request. In the example shown in FIG. 22B, the schedule response includes a series *1...k* of schedule sets, wherein each schedule set is comprised of an indication of a specific time frame (e.g., t1, t2, t3, ... tk) within a cycle or a super-cycle, along with an indication of the number of bytes (e.g., s1, s2, s3, ... sk) that can be transferred within that time frame.

FIG. 23 is a timing diagram illustrating the end-to-end synchronization within synchronous virtual pipe as provided by the present invention. In the specific example as shown in FIG. 23, a video frame is shown to be transferred from end-to-end in synchronization with a common time reference (e.g., UTC from GPS), but it is to be understood that FIG. 23 is only an example and the invention is not limited to the end-to-end synchronized transfer of video frames. As shown in FIG. 23, and end-station **Sender** is located on a first shared media network. The end-station **Sender** captures a video frame at time **1a** and provides any processing required to convert the video frame into a form suitable for direct digital transfer over a synchronous digital network. The details of such processing are well-known in the art and lie outside of the novelty of the present invention and thus will not be detailed herein.

The end-station **Sender** then transmits the data representing the video frame to the shared media network **Node B** at time frame **1b**. The transmission from **Sender** to **Node B** is scheduled apriori by interaction between **Sender** and **Node B** as shown in FIG. 20 and discussed above. The data comprising transmission **1b** is assembled into one or more associated data packets within the shared media network **Node B**.

The shared media network **Node B** forwards the data packet(s) through the synchronous virtual pipe connecting **Node B** to shared media network **Node C** at time frame **1c**. The transmission from **Node B** to **Node C** is scheduled apriori by interaction between **Node B** and **Node C** as part of the operation of setting up a synchronous

virtual pipe, which lies outside of the novelty of the present invention and thus will not be detailed herein. Note that as shown in FIG. 3, one synchronous virtual pipe may span a path containing a plurality of interconnected SVP switches **10** (e.g., **A**, **B**, **C**, **D**).

The shared media network **Node C** then forwards the data contained in the data packet(s) received at time frame **1c** from shared media network **Node C** to end-station **Receiver** at time frame **1d**. The transmission from shared media network **Node C** to end-station **Receiver** is scheduled apriori by interaction between **Node C** and end-station **Receiver** as shown in FIG. 21 and discussed above. The end-station **Receiver** accepts the video frame data at time **1e** and provides any processing required to convert the video frame data into a form suitable for display. The details of such processing are well-known in the art and lie outside of the novelty of the present invention and thus will not be detailed herein.

As shown in FIG. 23, a plurality of individual end-to-end transmissions may be in progress at any given time. In the example illustrated, during the time cycle containing time frame **1d**, the end-station Sender may process a second video frame at time frame **2a**, and thus relay the processed second video frame to the shared media network **Node B** at time frame **2b**. The present invention supports simultaneous pipelined synchronous operation such that, for example, time frames **2b** and **1d** may represent the same time frame numbers. It is to be understood that any number of simultaneous end-to-end transfers may be underway at the same time, subject to scheduling constraints due to bandwidth availability, which is clearly known apriori. Further, it is to be understood that because the schedules are established apriori, the indicated pipelined end-to-end operation is free of the problems inherent in the prior art regarding congestion and jitter.

FIG. 24A is a schematic block diagram of an end-to-end communication utilizing the shared media network of the present invention, and thus details another aspect of the end-to-end communication as shown in FIG. 23 and described above. In FIG. 24A, links **301** from a plurality of end-stations **300** (not shown) are coupled to the shared media network **200**. The shared media network **200** is coupled via link **101** to the access time manager **100**, which comprises part of the shared media network **B** of the present invention. The shared media network **B** additionally comprises an SVP switch **10** which further additionally comprises an output port **40**. The shared media network **B** is linked via a synchronous virtual pipe **25** to an input port **30** of the shared media network **D**, by way of any number of interstitial SVP switches (e.g., **C**) and links **41**. Note that as shown in FIG. 3 and previously described, one synchronous virtual pipe **25** may span a path containing a plurality of interconnected SVP switches **10**.

FIG. 24B is a timing diagram illustrating the timely transmission of data in the communication path shown in FIG. 24A, with the time axis directed downwards as

shown. Video frames are captured at times **1V/P**, **2V/P**, and **3V/P** and the data representative of the video frames are transported through the shared media network **200** to the shared media network **B** as shown in the figure. Times **1V/P**, **2V/P**, and **3V/P** are scheduled in advance using the protocol as shown in FIG. 20 and discussed above. Data packets containing data representative of video frames are then relayed via the synchronous virtual pipe **25** at scheduled times **1BCD**, **2BCD**, and **3BCD** (respectively) to shared media network **D**. The data representative of video frames are then relayed during times **1P/V**, **2P/V**, and (not shown) **3P/V**, respectively, to an end-station connected to one of the shared media networks available via shared media network **D**.

PACKET TELEPHONE SCHEDULING WITH DIFFERENT TIME INTERVALS

FIG. 26 is a schematic description VoIP gateway (GW) with streaming of digital samples in which the following functions are performed in its packeting subsystem controller **81**: (1) packetization (assembly of digital samples into data packets) and depacketization (separation of digital samples from data packets), (2) echo cancellation, and (3) compression and decompression. The controller **81** is constructed of a central processing unit (CPU), a random access memory (RAM) for storing the data packets and digital samples, a read only memory (ROM) for storing the controller processing program, and a table with forwarding and operation parameters. The packeting subsystem controller **81** is coupled to a synchronous virtual pipe (SVP) switch **10**. The controller **81** is also coupled via digital sample input links **82** and digital sample output links **83** to external voice, video, and other devices (not shown).

The SVP switch **10** of FIG. 26 is also coupled to one or more synchronous virtual pipes **41** by way of combination input/output ports **30/40**. The synchronous virtual pipes **41** can be implemented within an IP network.

The SVP switch **10** of FIG. 26 is further comprised of a GPS receiver **20** linked via a common time reference (CTR) signal **002** to each of the input/output ports **30/40**. In this manner, a common time reference is supplied to each of the input ports and each of the output ports within the SVP switch **10**. The CTR signal **002** is also coupled to the controller **81** as shown in the figure.

FIG. 27 is a schematic block diagram of a synchronous virtual pipe interface to a VoIP gateway as provided by the present invention, illustrating detail of an alternate embodiment. In this embodiment, the SVP switch **10** additionally comprises a switching fabric **50** which is coupled to one or more input ports **30** and one or more output ports **40**. Each of the input ports **30** is coupled to the switch fabric **50** via links **37**, as shown in FIG. 7. Each of the output ports **40** is coupled to the switch fabric **50** via links **51** as

shown in FIG. 9. The switch fabric is inherently coupled and integrated (not shown) to the controller **81**. Each pair of respective input port **30** and output port **40** comprise an input/output port **30/40**. As shown in FIG. 27, the common time reference (CTR) signal **002** is coupled to each input port **30**, each output port **40**, and to the controller **81**. The controller **81** is also coupled via digital sample input links **82** and digital sample output links **83** to external voice devices (not shown).

In yet another alternate embodiment, the operation of collection and assembly of data packets may additionally comprise the method of data compression, wherein the digital samples are compressed to further reduce the data packet bandwidth, or to reduce the data packet size required. In some cases the compression operation is performed on a group of block of digital samples with a predefined size or duration. In the case of data originating as visual (e.g. video signals), the compression operation may be performed on a group of block of digital samples within a predefined image region, size, or duration.

As shown in FIG. 28, the data packet is then transmitted **1b** via the SVP switch **10** to a synchronous virtual pipe during a predefined time frame. In the illustrated example, the set of digital samples assembled into a data packet are transmitted **1b** starting at time frame 1 of time cycle 1. The transmission **1b** occurs simultaneously with the start of the operation of collection and assembly of data packet **2a**, and the process repeats in time for subsequent time cycles.

FIG. 28 shows the timing of the regular collection and assembly of data packets and virtually immediate transmission of the data packet of digital samples of the present invention. Data packets are scheduled for immediate transmission within reserved time frames. thus congestion and routing latency within the initiating VoIP gateway are eliminated in the present invention.

FIG. 29 is a timing diagram illustrating the receipt, separation of digital samples from the data packets, and other processing of data packets of the present invention. The controller **81** is responsive to receipt of data packets comprising digital samples from a synchronous virtual pipe. The data packets arrive regularly **1d** at a predefined time frame in each time cycle, which is time frame 2 in the illustrated example. The separation **1e** of digital samples from the data packets is scheduled within the VoIP gateway of the present invention to immediately separate the digital samples from the data packet thus providing an output of digital samples. The output of digital samples is then relayed to an external device, which in the preferred embodiment for analog telephone is a digital to analog converter.

The regularity of arriving data packets at the same time frame of each time cycle provides for uninterrupted receipt of packets of digital samples, which in turn provides for uninterrupted receipt of digital samples at the digital to analog converter. The jitter

present in the received data packet arrival times is controlled by the common time reference to be very small and well-bounded. Because the separation of digital samples from a data packet can be scheduled to occur as soon as the data packet arrives at the VoIP gateway, the effects of latency on the data packets are minimized.

Further supporting telephone communications, the operations of collecting and assembling digital samples into data packets may additionally comprise an echo cancellation operation, in which copies of the digital samples are stored locally in a buffer, and then used in comparison with received digital samples. As a result of the comparison, an echo cancellation signal can be generated to eliminate or reduce the echo caused by the transmitted digital samples being attenuated and returned to the sender by voice equipment at the far end.

The echo cancellation process as described is an improvement over all prior art in that since both ends are based from the common time reference CTR signal **002**, and all other transit delays and jitter in the system are known apriori or are well-bounded, it is possible to very precisely align the stored samples with the retrieved samples in time.

It is another object of the present invention to convey multiple telephone communications via scheduled data packets over a synchronous virtual pipe. A preferred embodiment of the present invention schedules the assembly of a plurality of digital sample streams into data packets in coordination with the common time reference so that a data packet is complete and prepared for transmission within a scheduled respective time frame for all associated time cycles.

This scheduling is performed by taking a predefined and known amount of time that the assembly of a data packet will require and subtracting that from the scheduled time frame. If the assembly of digital samples into a data packet starts at the scheduled start time, it will complete just in time for transmission on the scheduled time frame over the synchronous virtual pipe. It is to be appreciated that this scheduling reduces the latency incurred by each data packet to the minimum possible; and that since data packets are conveyed by a synchronous virtual pipe, the jitter of the arrival times of the data packets at their destination is well-defined and bound to a small value. In fact, the jitter can be reduced to timing error associated with the clock signal from GPS, which can be maintained below one microsecond. Both minimal latency and minimal jitter are requirements for conveying telephone communications and other real-time audio, visual, and audiovisual streams via data packets.

The scheduled assembly takes the digital samples from a plurality of digital sample streams and collects and assembles them into a data packet. The data packet thus can contain a fragment of a plurality of simultaneously occurring telephone communications or other types of real-time streams. The data packet may then be routed via a synchronous virtual pipe to its destination. The method of combining

multiple telephone communications together into a data packet provides for reducing the cost of the overhead associated with transmitting each telephone conversation, as the overhead of collection, assembly into data packets, and routing is then shared among all the telephone communications conveyed within the same data packet. This combining is practical for telephone communications primarily because of the low data rate requirements associated with voice telephone communications. In one embodiment, the overhead associated with transmitting a data packet is fixed at 40 bytes. In this embodiment, collecting ten incoming voice streams could be assembled into data packets and routed together, thus reducing the effective overhead for any one stream of digital samples to 4 bytes, or alternatively, reducing the delay associated with collection and assembly of digital samples into data packets.

FIG. 30 is a timing diagram illustrating multiplexing of multiple real-time streams (e.g., telephone calls) into one data packet in the present invention. The controller **81** is responsive to receipt of multiple streams of digital samples and collects and assembles the samples over time into a data packet. The collection and assembly of digital samples **1a**, **1a'**, **1a''** into a data packet is shown to start within time frame 1 of time cycle 0 in the example timing of FIG. 30. As shown, the collection and assembly of a data packet can complete within an interval less than or equal to the duration of one time cycle, and therefore repeats the process beginning and ending at the same relative time frames within the associated time cycles for each time cycle. In the illustrated example timing, the collection and assembly of digital samples into a data packet **1a** completes 99 time frames later, in time frame 100 of time cycle 0.

In an alternate embodiment, the operation of collection and assembly of digital samples into a data packet may additionally comprise the method of converting analog voice signals into digital samples for one or more of the streams of digital samples, prior to assembling the digital samples into a data packet. In this alternate embodiment, the scheduling also factors in the additional time required to receive the converted digital samples from the analog to digital converter.

The data packet representing the digital sample inputs **1a**, **1a'**, **1a''** is then transmitted **1b** via the SVP switch **10** to a synchronous virtual pipe during a predefined time frame. In the illustrated example, the data packet of digital samples assembled at **1a** are transmitted **1b** starting at time frame 1 of time cycle 1. The transmission **1b** occurs simultaneously with the start of the operation of collection and assembly of digital samples into a new data packet of new samples **2a**, **2a'**, **2a''**, and the process repeats in time for subsequent time cycles.

FIG. 31 is a timing diagram illustrating demultiplexing of data packets into multiple streams (e.g., telephone calls) in the present invention. The controller **81** is responsive to receipt of data packets comprising a plurality of streams of digital samples

from a synchronous virtual pipe. The data packets arrive regularly **1d** at a predefined time frame in each time cycle, which is time frame 3 in the illustrated example. The separation of digital samples from the data packet of streams of samples **1e**, **1e'**, **1e''** is scheduled, within the VoIP gateway of the present invention, to provide immediate separation of the data packet for each output stream thus providing a plurality of outputs of digital samples. Each output of digital samples is then relayed to an external device, which in the preferred embodiment are digital to analog converters supporting, for example, a conventional analog telephone. In an alternate embodiment, the external device can be a digital phone, a digital video display, or any other form of digital audio, visual, or audiovisual device..

The regularity of arriving data packets at the same time frame of each time cycle provides for uninterrupted receipt of packets of digital samples, which in turn provides for uninterrupted receipt of multiple streams of digital samples at each of the digital to analog converters. The jitter present in the received data packet arrival times is controlled by the common time reference to be very small and well-bounded. Because the separation of digital samples from the data packet can be scheduled to occur as soon as the data packet arrives at the VoIP gateway, the effects of latency on the data packets are minimized.

As shown in FIGS. 30-31, this embodiment of the present invention permits multiple telephone communications to be conveyed via a single synchronous virtual pipe. One or more telephone communications are assembled together into data packets and the respective data packets are forwarded at predefined time frames through a synchronous virtual pipe to a destination, where the digital samples in the data packets are separated and directed to respectively one or more telephone communication destinations. The present invention permits telephone conversations to thus be trunked via synchronous virtual pipes to reduce the overhead associated with assembly of data packets and conveyance of data packets. This reduction in overhead is practical as a result of the relatively low data rate required for voice telephone communications.

It is to be appreciated that multiple telephone communications can be independently converted, collected, and assembled into data packets in accordance with the description above for a single telephone communication, such that each of the multiple telephone communications results in a corresponding respective set of data packets. Each of the data packets is thus independently scheduled and transmitted over the synchronous virtual pipe. The scheduling may transmit multiple data packets within one or more time frame. Assembly of multiple streams of voice data independently into multiple data packets is an optional method of operation when the telephone communications are permitted to travel over the same synchronous virtual pipe to a similar destination.

FIG. 32 illustrates both a schematic block diagram of an end-to-end VoIP connection showing one implementation of a trunked phone communication as described above and with respect to FIGS. 30-31, and also shows a composite timing diagram showing end-to-end timing illustrating the timing of the schematic block diagram of an end-to-end VoIP connection. In the illustrated figure, multiple streams of digital samples are conveyed to the controller **81** of VoIP gateway A **80** via digital sample inputs **82**. The VoIP gateway **80** additionally comprises, as described above, an output port **40** coupled via communication link **41** to zero or more SVP switches **10**, e.g. B, C. The zero or more SVP switches **10** comprise a virtual pipe **25**, wherein each of the switches **10** is coupled to the next switch **10** in the virtual pipe **25** by a link **41**.

The virtual pipe begins at VoIP gateway A **80** and ends at VoIP gateway D **80** which as described above incorporates an input port **30** and a controller **81**. The controller **81** couples a plurality of outgoing streams of digital samples via links **83**.

The bottom of FIG. 32 illustrates a timing diagram of the operation of the logical connection as shown in the top of FIG. 32. Time progresses in the downward direction in this timing diagram.

Conversion of analog voice to digital samples and the assembly of same digital samples into data packets occurs at times **1A/D**, **2A/D**, and **3A/D** as shown in the figure. These conversion and assembly operations are scheduled to start once per time cycle at a predefined time frame.

The data packets enter the synchronous virtual pipe at the output port **40** of the VoIP gateway A **80** in order and once per time cycle at a predefined time frame. The transmission of data packets via the synchronous virtual pipe is scheduled to occur once each time cycle at a predefined time frame. The actual transit times of data packets via the synchronous virtual pipe are shown as **1BCD**, **2BCD**, and **3BCD** in FIG. 32. Due to the nature of the synchronous virtual pipe, the data packets arrive in order and once per time cycle at predefined time frames at the input port **30** of the destination VoIP gateway D **80** as shown in FIG. 32.

The separation of digital samples from the data packets and conversion of digital samples to analog voice occurs during time intervals **1D/A**, **2D/A**, and **3D/A** as shown. The separated digital samples are then routed simultaneously to the appropriate digital output links **83**.

FIG. 26 illustrates the structure of a VoIP gateway of the present invention. The VoIP gateway **80** is comprised of a controller **81** coupled to an SVP switch **10**. The controller **81** is also coupled via digital sample input links **82** and digital sample output links **83** to external voice devices (not shown).

FIG. 26 illustrates the structure of a VoIP gateway of the present invention. The VoIP gateway **80** is comprised of a controller **81** coupled to an SVP switch **10**. The

controller **81** is also coupled via digital sample input links **82** and digital sample output links **83** to external (e.g., voice) devices (not shown).

FIG. 33 is a schematic block diagram of time frame call multiplexing using headerless time-based routing of the present invention. The left half of FIG. 33 illustrates the structure of an alternate embodiment of the VoIP gateway. The VoIP gateway **80** is comprised of a controller **81** coupled to an SVP switch **10**. The controller **81** is also coupled via digital sample input links **82** and digital sample output links **83** to external voice devices (not shown). The SVP switch **10** of FIG. 33 is also coupled to one or more synchronous virtual pipes **41** by way of combination input/output ports **30/40**.

The SVP switch **10** of FIG. 26 is further comprised of a GPS receiver **20** linked via a common time reference (CTR) signal **002** to each of the input/output ports **30/40**. In this manner, a common time reference is supplied to each of the input ports and each of the output ports within the SVP switch **10**. The CTR signal **002** is also coupled to the controller **81** as shown in the figure.

The right half of FIG. 33 illustrates the timing of selected synchronous virtual pipes associated with the links **41**. In the alternate embodiment of FIG. 33, the synchronous virtual pipes relay stripped data packets consisting solely of a payload portion. The header portion typically associated with data packets is not present with a stripped data packet. The links **41**, which may each contain zero or more SVP switches **10** as previously described, convey stripped data packets using a time-based routing method.

FIGS. 33-34 depict a common time reference (CTR) **002** axis that is divided into time cycles. Each time cycle is divided into predefined time frames. Each of the time frame has predefined positions: **a**, **b**, **c**, and **d** of either fixed size (in time duration) or variable size (in time duration), consequently, the predefined position can have either fixed size data packets or variable size data packets, respectively. Each time frame can be further divided into time slots. Time frames utilize packet delimiters (PDs) **35C**. The PDs can be one of the control codewords as shown in FIG. 5C. PDs are used to indicate separations; packet delimiters can then be used to distinguish between multiple headerless data packets in the same time frames; and when using PDs in headerless time-based routing, the headerless data packets are permitted to have zero length. Time slots have a predetermined length or lengths and do not use packet delimiters. In an alternate embodiment, time slots may be delimited using a different delimiter than the one used as PDs.

When using the time-based or position-based routing method of the alternate embodiment of the present invention, the position of the stripped data packet within a time cycle determines its destination. As shown symbolically in the right side of FIG.

33 and in FIG. 34, stripped data packets **a**, **b**, **c**, and **d** in each time slot are respectively in the four consecutive time slots or positions within each time frame. Each first time slot or position in any time frame contains stripped data packets **a**, each second time slot or position in any time frame contains stripped data packets **b**, and so on as shown in the figure. The operation of the routing controller **35** in the present embodiment is similar to that shown in FIG. 7, except that the values used to index into the lookup table **35D** is a time slot or position counter maintained by the controller **35B** responsive to the packet delimiter signal **35C**. In one variant embodiment, the value of the time slots within a time frame and the time frames within a time cycle may be alternatively defined by an in-band control codeword signal as discussed above.

The present invention permits use as a call center, routing telephone communications from a plurality of origination points to a plurality of destination points and vice versa. This operation may include multi-party conference calls, using the multicasting routing provided by the switches in the synchronous virtual pipe of the present invention. Providing a conference call capability for large numbers of users is made easier by the use of a common time reference signal to coordinate the analog to digital conversion, the multiplexing, the assembly, the switching and routing, the separation, the demultiplexing, and the digital to analog conversion all to the same common timebase.

From the foregoing, it will be observed that numerous variations and modifications may be effected without departing from the spirit and scope of the invention. It is to be understood that no limitation with respect to the specific apparatus illustrated herein is intended or should be inferred. It is, of course, intended to cover by the appended claims all such modifications as fall within the scope of the claims.

WHAT IS CLAIMED IS:

1. A system for scheduling and managing data transfer of data packets, said system comprising:

a plurality of switches with plurality of input ports and output ports, each with a unique address for receiving the data packets;

a plurality of at least one virtual pipe each comprising at least two of the switches interconnected via communication links in a path, for transferring the data packets from at least one source to at least one destination; and

a common time reference signal coupled to some of said switches;

wherein the common time reference is partitioned into time frames, and wherein the transfer of the data packets is provided during respective ones of a plurality of predefined time frames;

wherein the time frames have at least one predefined duration;

wherein each of the respective data packets is received by a first input port and transmitted by a second output port, and wherein the time frame used by the first input port has a first predefined duration and the time frame used by the second output port has a second predefined duration; and the system is further comprising:

a scheduling controller for mapping from a first predefined time frame with the first predefined duration, within which the respective data packet is transferred into the respective switch, to a second predefined time frame with the second predefined duration, within which the respective data packet is transmitted out of the respective switch, wherein said scheduling controller is responsive to the common time reference signal.

2. The system as in claim1, wherein the position of said data packet within said second predefined time frame is arbitrary.

3. The system as in claim 1, wherein the time frame used by the input port has a first predefined duration and the time frame used by the output port has a second predefined duration.

4. The system as in claim 3, wherein the time frames of the first predefined duration are longer than the time frames of the second predefined duration.

5. The system as in claim 1, wherein a predefined number of contiguous time frames comprise a time cycle; and

wherein the time cycles are contiguous.

6. The system as in claim 1, wherein a first number of contiguous time frames of a first predefined duration comprise a time cycle of a third predefined duration;

wherein the time cycles of the third predefined duration are contiguous;

wherein a second number of contiguous time frames of the a second predefined duration comprise a time cycle of a fourth predefined duration; and

wherein the time cycles of the fourth predefined duration are contiguous.

7. The system as in claim 6, wherein the time cycle of the third predefined duration is equal to the time cycle of the fourth predefined duration.

8. The system as in claim 6, wherein the time cycle of the third predefined duration is larger than the time cycle of the fourth predefined duration.

9. The system as in claim 6, wherein the time cycle of the third predefined duration is smaller than the time cycle of the fourth predefined duration.

10. The system as in claim 6, wherein a third number of time cycles of the third predefined duration comprise a first super cycle;

wherein the first super cycles are contiguous;

wherein a fourth number of time cycles of the fourth predefined duration comprise a second super cycle; and

wherein the second super cycles are contiguous.

11. The system as in claim 10, wherein the first super cycle and the second super cycle have equal durations.

12. The system as in claim 10, wherein the first super cycle and the second super cycle start at a same time with respect to the common time reference.

13. The system as in claim 10, wherein the first super cycle and the second super cycle have different durations.

14. The system as in claim 5, wherein a fixed number of a plurality of contiguous ones of the time cycles comprise a super cycle; wherein the super cycle is periodic.

15. The system as in claim 1, wherein the common time reference signal is coupled from a Global Positioning System (GPS).

16. The system as in claim 1, wherein the common time reference signal is in accordance with the Coordinated Universal Time (UTC) standard.

17. The system as in claim 15, wherein the super cycle duration is equal to one second as measured using the Coordinated Universal Time (UTC) standard.

18. The system as in claim 1, wherein the transmission over each of said communication links is provided during a time frame with a duration selected from a plurality of predefined time frame durations.

19. The system as in claim 1, wherein the mapping by the scheduling controller provides consistent fixed time frames between the input to and output from at least a selected one of the plurality of virtual pipes.

20. The system as in claim 1, wherein the transmission over at least a selected one of the plurality of virtual pipes utilizes a plurality of time frame durations.

21. The system as in claim 1, wherein a predefined number of contiguous time frames of the first predefined duration comprise a time cycle of a fifth predefined duration;

wherein the time cycles of the fifth predefined duration are contiguous;

wherein a predefined number of contiguous time frames of the second predefined duration comprise a time cycle of a sixth predefined duration;

wherein the time cycles of the sixth predefined duration are contiguous;

wherein a predefined number of contiguous time frames of a third predefined duration comprise a time cycle of a seventh predefined duration; and

wherein the time cycles of the seventh predefined duration are contiguous.

22. The system as in claim 21, wherein the transmission over at least a selected one of the plurality of virtual pipes utilizes at least one of a time cycle of the fifth predefined duration, a time cycle of the sixth predefined duration, and a time cycle of the seventh predefined duration.

23. The system as in claim 21, wherein there are more than three different time frame durations; and

wherein there are more than three different time cycle durations.

24. The systems as in claim 1, wherein each time frame at each of the input ports is grouped into time cycles, wherein each time frame duration at each of the input ports has one of a plurality of predefined durations;

wherein the time frames at each of the output ports is grouped into time cycles, wherein each time frame duration at each of the output ports has one of a plurality of predefined durations; and

a switching fabric for coupling incoming data packets between selected ones of the input ports and the output ports, wherein each of the selected input ports has an associated first time frame duration, and wherein each of the selected output ports has an associated second time frame duration.

25. The systems as in claim 24, wherein one or more data packets can be communicated within each of the time frames.

26. The systems as in claim 24, wherein a predefined number of contiguous i1 time frames of duration d1 at a first input port are grouped into a time cycle ic1, wherein i1 is at least 1;

wherein a predefined number of contiguous i2 time frames of duration d2 at a second input port are grouped into a time cycle ic2, wherein i2 is at least 1;

wherein a predefined number of contiguous i3 time frames of duration d3 at a third input port are grouped into a time cycle ic3, wherein i3 is at least 1;

wherein a predefined number of contiguous o1 time frames of duration t1 at a first output port are grouped into a time cycle oc1, wherein o1 is at least 1;.

wherein a predefined number of contiguous o2 time frames of duration t2 at a second output port are grouped into a time cycle oc2, wherein o2 is at least 1;

wherein a predefined number of contiguous o3 time frames of duration t3 at a

third output port are grouped into a time cycle oc3, wherein o3 is at least 1;

wherein the scheduling of data packets on the input ports and output ports of the switch have plurality of predefined mapping from: i1-in-ic1 and i2-in-ic2 and i3-in-ic3 to o1-in-oc1 and o2-in-oc2 and o3-in-oc3.

27. The system as in claim 26, further comprising:

a routing controller with a routing table for selecting at least one output port that said respective data packets will be forwarded to;

wherein the routing controller attaches a time of arrival (ToA) to incoming data packets at the input port using the predefined time frame duration and the time cycle associated with the respective input port;

wherein the time of arrival (ToA) relates to the common time reference and is represented as a time frame number within a time cycle; and

wherein the ToA has a unique representation on each of at least the first input port, the second input port, and the third input port.

28. The system as in claim 27, wherein after the incoming data packet is transferred to one of the output ports, the ToA unique representation is utilized to transform to a unique output port representation on each of at least the first output port, the second output port, and the third output port.

29. The system as in claim 28, further comprising:

a memory partitioned into plurality of buffers; and

a scheduling controller for selecting one of the plurality of buffers;

wherein the unique output port representation is used by the scheduling controller to select one of the plurality of buffers.

30. The system as in claim 29,

wherein each of the buffers is uniquely associated with one of the time frames; and

wherein said one of the time frames is the time the data packet is forwarded from the output port.

31. The system as in claim 1, further comprising:

a controller system, for scheduling transfer of data packets between one of a point to point network and a shared medium, and an end station and the shared medium;

a first scheduling controller for scheduling of a first time frame for the transfer of the data packets from the shared medium to the point to point network, responsive to the common time reference signals; and

a second scheduling controller for scheduling a time interval for the transfer of the data packets from the end station to the shared medium, responsive to the first scheduling controller;

wherein the time interval occurs immediately before the first time frame.

32. The system as in claim 31, wherein the first and the second scheduling controllers schedule their respective data transfer in alternating sequential time order to effectuate the transfer of a plurality of the data packets over a plurality of the first time frames and a plurality of the time intervals.

33. The system as in claim 31, further comprising an access time manager, wherein the first and the second scheduling controllers are part of the access time manager.

34. The system as in claim 31, wherein the time frames are structured into a time cycle comprised of a fixed number of contiguous time frames, which are structured into a stream of a plurality of contiguous time cycles.

35. The system as in claim 34, wherein the scheduling of transmission of respective data packets occurs at a defined one of the time frame positions within each of the time cycles.

36. The system as in claim 35, wherein the scheduling of transmission of respective data packets to the point-to-point network occurs at multiple defined ones of the time frame positions within each of the cycles.

37. The system as in claim 31, wherein there are a plurality of end-stations;

wherein the second scheduling controller schedules a plurality of time intervals for the transfer of plurality of data packets from the end-stations to the shared media network.

38. The system as in claim 37, wherein the transfer of plurality of data packets from the end-stations to the shared media network is responsive to the first scheduling controller.

39. The system as in claim 31, wherein the second scheduling controller is part of the end-station.

40. The system as in claim 39, the first scheduling controller further comprising TICK sending means for sending TICK signals, the second scheduling controller further comprising TICK receiving means for receiving TICK signals;

wherein the transfer of data packets from the end station to the shared media network is regulated by the second scheduling controller responsive to the TICK signals.

41. The system as in claim 31, wherein the shared media network is at least one of an IEEE P1394 room network, an Ethernet local area network, a Data-Over-Cable Service Interface Specification (DOCSIS) cable modem network, an IEEE 802.14 cable modem network, an IEEE 802.11 wireless network, a Fiber Channel Arbitrated Loop (FC-AL) storage area network, and an Serial Storage Association (SSA) storage area network.

42. The system as in claim 31, wherein the end-station is at least one of a video camera, a video cassette recorder (VCR), a video disk, a set-top box, a set-top box with

Ethernet connection to video camera and VCR, a desktop computer, a mobile unit, a disk drive, a tape drive, a semiconductor disk, an electronic disk, a telephone set, a video display, a video game input and output, and a computer work-station.

43. The system as in claim 31, wherein the second scheduling controller is part of at least one of the following: a cable-modem head-end, a wireless network base station, an IEEE 1394 shared media network, and a host adapter for storage area network.

44. The system as in claim 1, further comprising:

a source for transmitting periodic data bursts;

a destination for receiving periodic data bursts;

a first shared media network, coupled to the source for transmitting periodic data bursts and to the virtual pipe; and

a second shared media network, coupled to the virtual pipe and to the destination for receiving periodic data bursts.

45. The system as in claim 44, wherein the first shared media network is coupled to the input of the virtual pipe; and

wherein the second shared media network is coupled to the output of the virtual pipe.

46. The system as in claim 44,

wherein there are a plurality of virtual pipes;

wherein the first shared media network is coupled to the input of the a first virtual pipe and is coupled to the output of the a second virtual pipe; and

wherein the second shared media network is coupled to the input of the a third virtual pipe and is coupled to the output of the a fourth virtual pipe.

47. The system as in claim 44, wherein the periodic data bursts represent captured video frames by a video camera.

48. The system as in claim 44, wherein the destination for receiving periodic data bursts provides for a display of video frames responsive to the respective periodic data bursts.

49. The system as in claim 48, wherein there are a plurality of destinations for receiving the periodic data bursts, each providing for a respective display of video frames to a respective display.

50. The system as in claim 48, wherein the display is at least one of a television (TV) set, a high definition TV (HDTV) set, a computer monitor, a flat panel display, a movie theater, a video display in a conference room, and a hand-held wireless video display.

51. The system as in claim 44, further comprising a scheduling controller for defining one or more predefined time frames, and for scheduling the a synchronous transfer of the periodic data bursts commencing during respective scheduled ones of the time frames occurring closest in time to an occurrence of the respective periodic data

bursts from the source.

52. The system as in claim 51, wherein the synchronous transfer is from the source to the destination.

53. The system as in claim 51, wherein the source is coupled to at least one of a first IEEE 1394 shared media network, a first cable-modem system, and a second IEEE 1394 shared media network that is coupled to a second cable-modem system;

wherein the display is coupled to the destination via at least one of a third IEEE 1394 shared media network, a third cable-modem system, and a fourth IEEE 1394 shared media network that is coupled to a fourth cable-modem system.

54. The system as in claim 44, wherein the periodic data bursts have complex periodicity.

55. The system as in claim 54, wherein a predefined number of contiguous k time frames are grouped into a time cycle, wherein k is at least 1;

wherein a predefined number of contiguous l time cycles are grouped into a super cycle, and wherein l is at least 1;

wherein the source of periodic data bursts are scheduled for transmission in reoccurring predefined time frames in selected ones of said time cycles and super cycles.

56. The system as in claim 55, wherein the periodic data bursts are scheduled for transmission in reoccurring predefined time frame positions within selected ones of the time cycles within each of the super cycles.

57. The system as in claim 1, further comprising:

a source of a stream of digital samples;

a packeting subsystem for providing packetization of a plurality of the digital samples into a data packet; and

a controller for defining a plurality of predefined time frames responsive to the common time reference signal, and for scheduling of transmission of associated respective ones of the data packets at respective selected ones of the predefined time frames;

wherein the packeting subsystem provides packetization responsive to the controller, and wherein the packetization of each of the respective ones of the data packets is scheduled for completion prior to the respective selected predefined time frame.

58. The system as in claim 57, wherein each respective one of the data packets is output from the gateway system during the respective selected predefined time frame.

59. The system as in claim 57, wherein, for each respective one of the data packets, the packetization of the plurality of the digital samples into the data packets is completed immediately prior to the respective selected predefined time frames.

60. The system as in claim 57, wherein the time frames are scheduled and structured into a time cycle comprised of a fixed number of contiguous time frame positions which are structured into a stream of a plurality of contiguous time cycles.

61. The system as in claim 60, wherein the scheduling of transmission of respective data packets occurs at a defined one of the time frame positions within each of the time cycles.

62. The system as in claim 61, wherein the scheduling of transmission of respective data packets occurs at multiple defined ones of the time frame positions within each of the cycles.

63. The system as in claim 57, wherein the stream of digital samples are at least one of digitized analog voice telephony, digitized uncompressed voice telephony, digitized compressed voice telephony, narrowband Integrated Service Digital Networks (ISDN), video, television (TV), high definition TV (HDTV), and high fidelity (Hi-Fi) audio.

64. The system as in claim 57, wherein there are a plurality of streams of digital samples; and

wherein the packeting subsystem provides for packetization of the data packets for each of the plurality of streams.

65. The system as in claim 64, wherein the packeting subsystem provides for the packetization of the plurality of the digital samples from the plurality of the streams of digital samples into a single data packet; and

wherein the packetization starts and ends synchronous to the common time reference signals.

66. The system as in claim 65, wherein each of the respective data packets further comprises a payload with plurality of predefined positions; and

wherein there is one respective predefined position in said payload for each of the streams for the digital samples from each of the streams in the respective data packet.

67. The system as in claim 66, wherein each one of the predefined positions has an associated predefined maximum length.

68. The system as in claim 66, wherein a position delimiter is provided between each of the predefined positions.

69. The system as in claim 66, wherein each one of the predefined positions has an associated respective predefined position number, wherein the controller uniquely associates the position number with a respective one of the plurality of streams of digital samples.

70. The system as in claim 66, wherein each of the predefined positions has an identifier uniquely associated with a respective one of the plurality of streams of digital samples.

71. The system as in claim 57, wherein a time reference of defined positions within

defined time frames is determined responsive to the common time reference signals;

wherein the packeting subsystem provides means wherein each of the data packets is assigned an associated one of the defined positions within a one of the defined time frames, responsive to the common time reference signals.

72. The system as in claim 57, wherein each of the time frames is comprised of a plurality of predefined positions;

wherein there are a plurality of streams of digital samples;

wherein the packeting subsystem provides for the packetization of a plurality of the digital samples from each one of a respective plurality of the streams of digital samples; and

wherein the respective digital samples from each one of the respective streams has one respective predefined position in said time frame.

73. The system as in claim 1, further comprising:

a first voice over Internet Protocol (IP) gateway and wherein a final switch within the virtual pipe is connected to provide an output coupled to transmit to a second voice over IP gateway,

wherein the common time reference signal is coupled to the first and the second voice over IP gateway;

a controller for determining a plurality of predefined time frames responsive to the common time reference signal, and for determining a schedule of selected ones of the predefined time frames for packetization of respective packetized data during the selected ones of the predefined time frames; and

wherein the second voice over IP gateway is comprised of a depacketizing subsystem for depacketizing the packetized data to provide an output of a plurality of digital samples, responsive to the controller.

74. The system as in claim 73, wherein the depacketization subsystem completes the depacketization prior to the respective predefined time frame associated with the packetization of the respective packetized data, responsive to the controller.

75. The system as in claim 73, wherein the packetized data is comprised of data from a plurality of separate original streams of digital samples;

wherein the depacketizing system provides for the depacketization of the packetized data into a plurality of separate streams of digital samples corresponding to the respective separate original streams of the digital samples.

76. The system as in claim 73, wherein the packetized data is comprised of a plurality of sub-units, each associated with a separate one of the streams of digital samples, with each sub-unit delimited from other adjacent sub-units by a position delimiter;

wherein the depacketizing subsystem is responsive to the position delimiters for

separating the respective packetized data into the respective associated plurality of separate streams of the digital samples.

77. The system as in claim 75, wherein the packetized data has a predefined structure that is comprised of a plurality of predefined sub-units of predefined size;

wherein the depacketizing subsystem provides the depacketization into the plurality of separate streams of digital data responsive to the predefined structure.

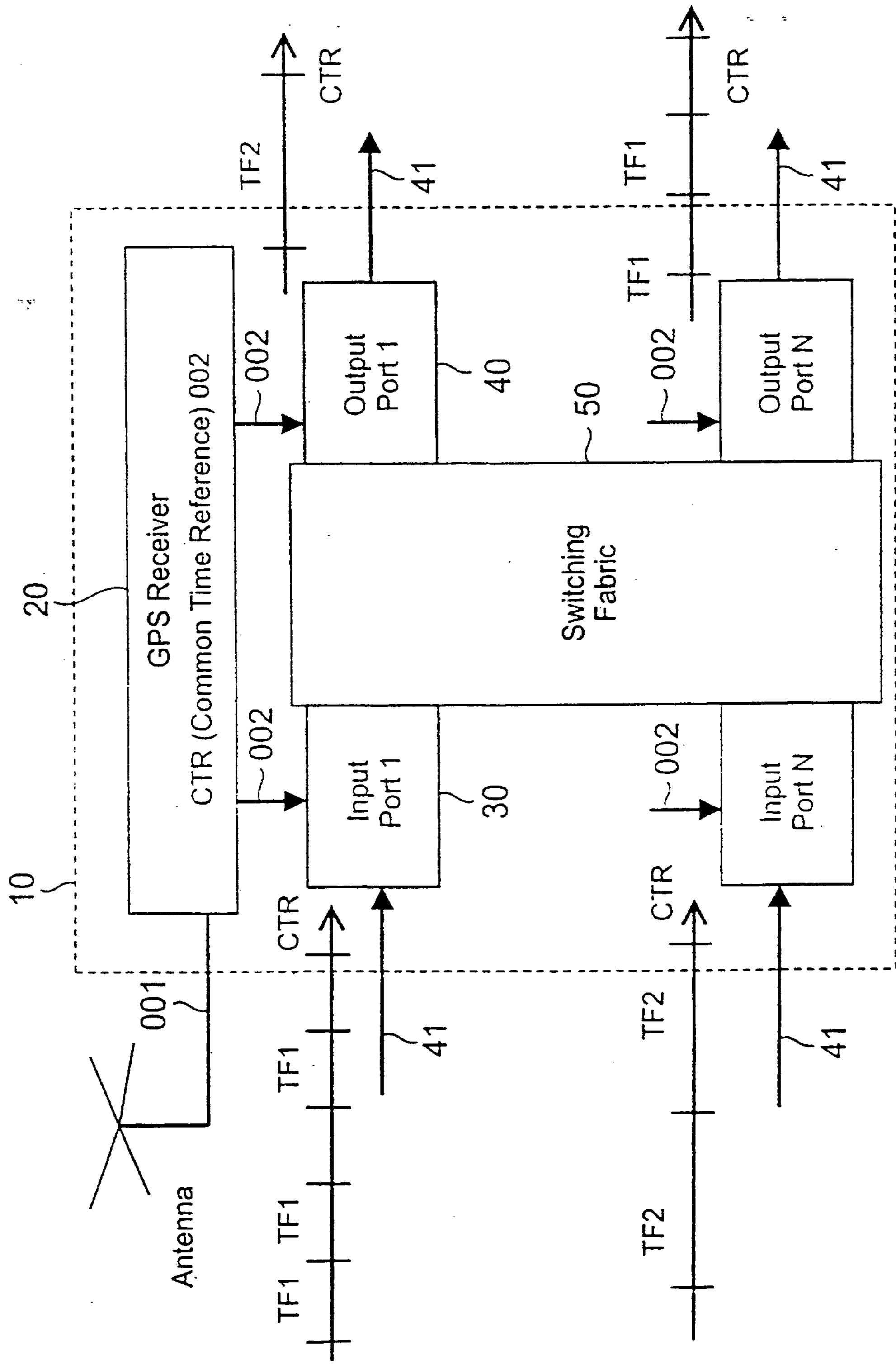

10
20
GPS Receiver
CTR (Common Time Reference) 002
001
Antenna
002
002
Input Port 1
30
Output Port 1
40
Switching Fabric
50
Input Port N
Output Port N
002
002
CTR
TF1
TF1
TF1
TF2
TF2
CTR
41
41
41
41
TF2
CTR
TF1
TF1
CTR

FIG. 1

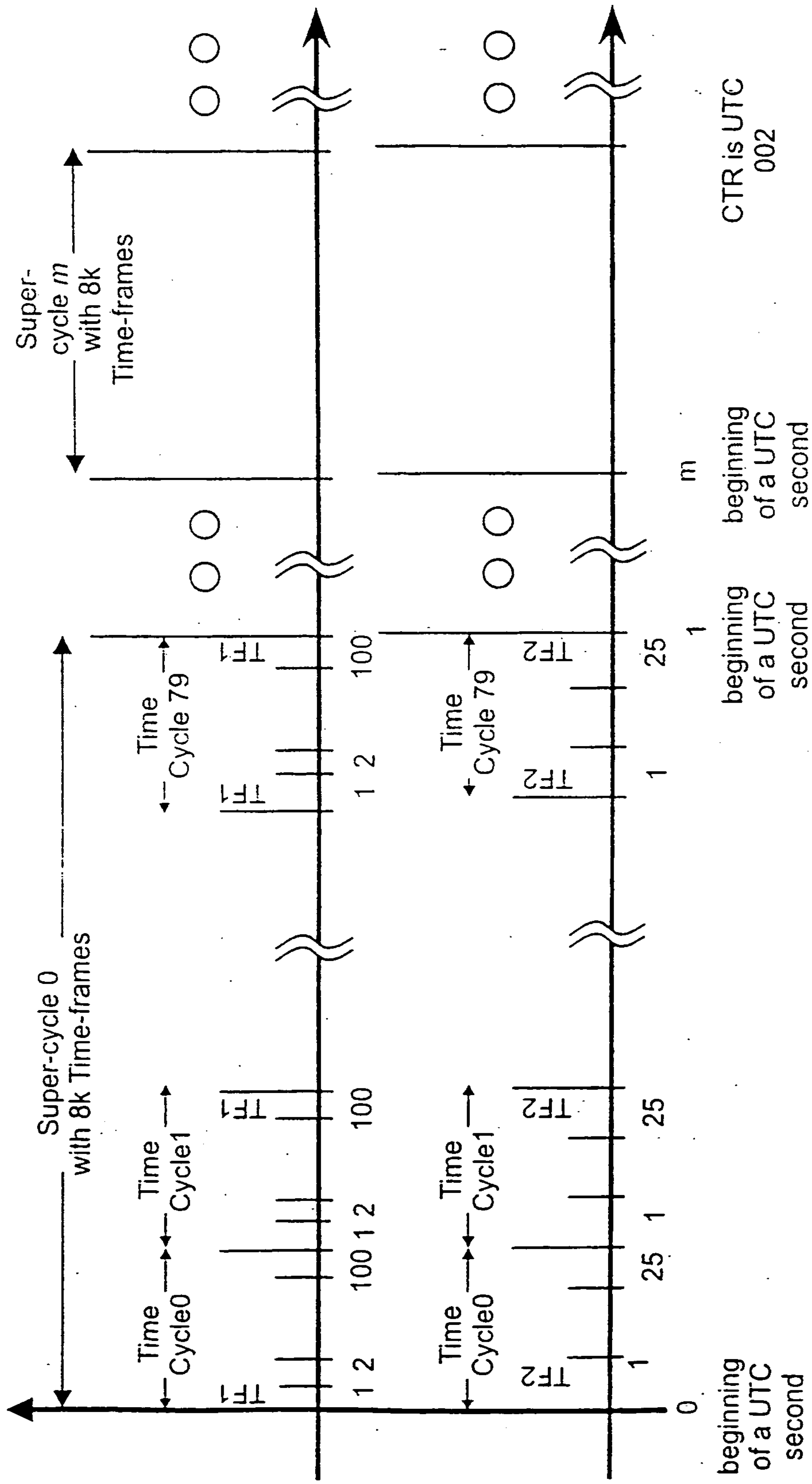

Super-cycle 0
with 8k Time-frames
Super-
cycle m
with 8k
Time-frames
Time
Cycle0
Time
Cycle1
Time
Cycle 79
TF1
TF2
1 2
100
1
25
0
beginning
of a UTC
second
1
beginning
of a UTC
second
m
beginning
of a UTC
second
CTR is UTC
002

FIG. 2

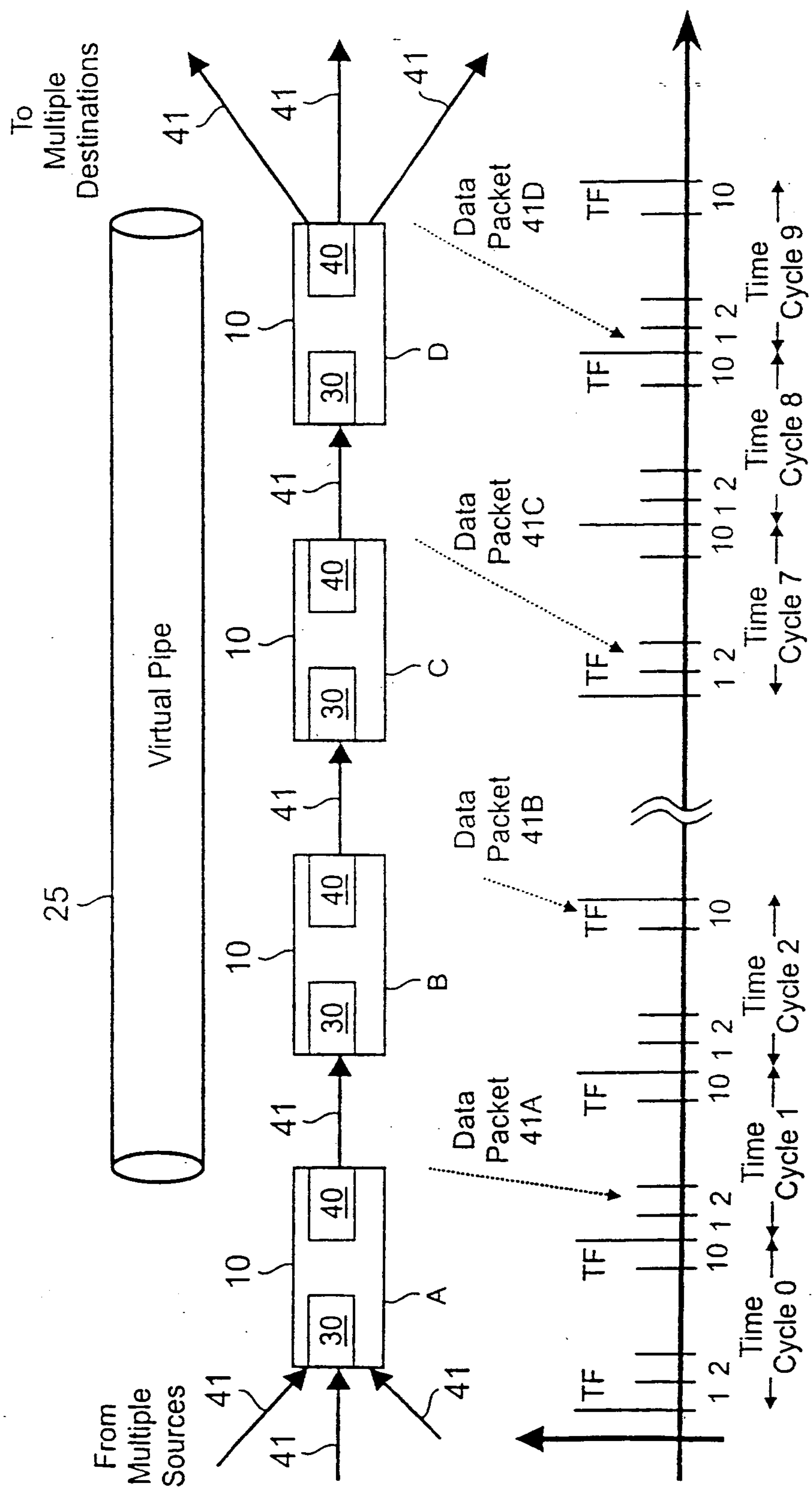

To Multiple Destinations
41
41
41
25
Virtual Pipe
10
30
40
A
B
C
D
From Multiple Sources
Data Packet 41A
Data Packet 41B
Data Packet 41C
Data Packet 41D
TF
Time Cycle 0
Time Cycle 1
Time Cycle 2
Time Cycle 7
Time Cycle 8
Time Cycle 9

FIG. 3

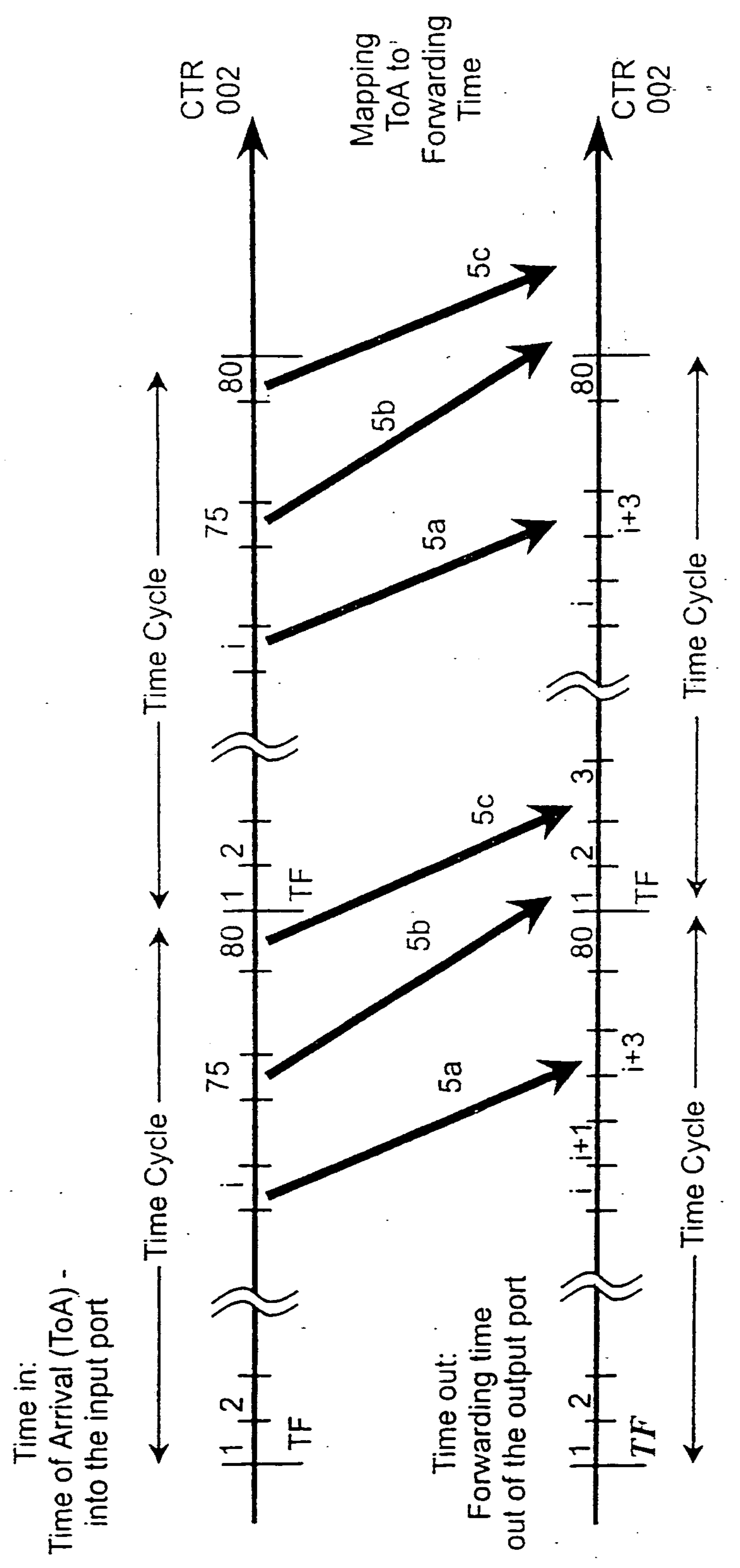
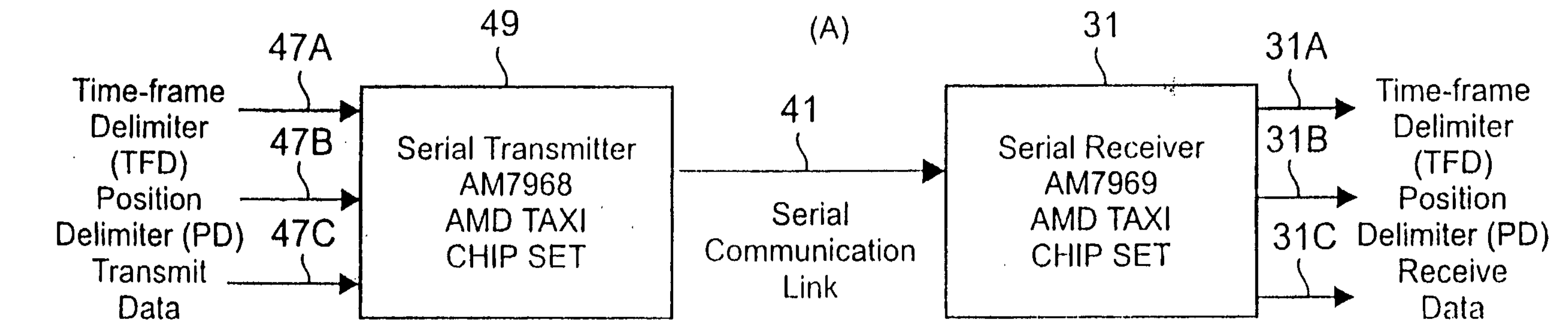

CTR
002
Mapping
ToA to
Forwarding
Time
CTR
002
Time in:
Time of Arrival (ToA) -
into the input port
Time out:
Forwarding time
out of the output port
Time Cycle
Time Cycle
Time Cycle
Time Cycle
TF
TF
TF
TF
1
2
i
75
80
i+1
i+3
3
5a
5b
5c

FIG. 4

(A)



(B)

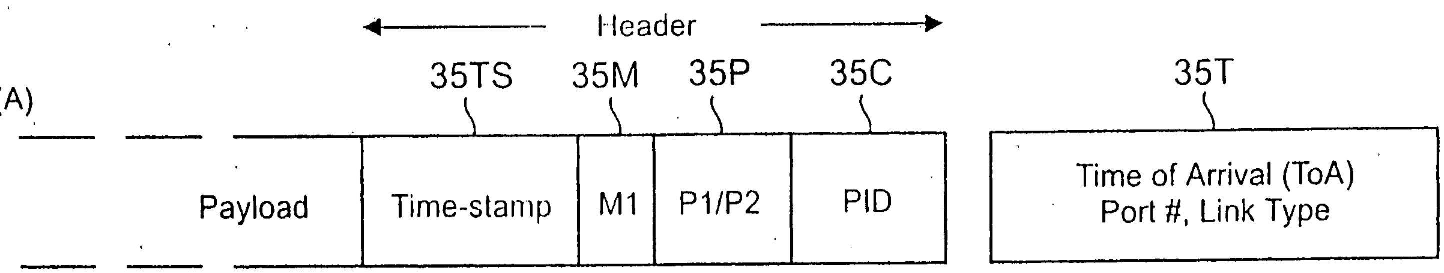
4B/5B encoding scheme		
HEX DATA	4-bit Binary Data	5-bit Encoded Data Codeword
0	0000	11110
1	0001	01001
2	0010	10100
3	0011	10101
4	0100	01010
5	0101	01011
6	0110	01110
7	0111	01111
8	1000	10010
9	1001	10011
A	1010	10110
B	1011	10111
C	1100	11010
D	1101	11011
E	1110	11100
F	1111	11101

(C)

4B/5B encoding scheme			
Control Input		10-bit Encoded Control Codeword	
HEX DATA	Binary Data		
1	0001	11111	11111
2	0010	01101	01101
3	0011	01101	11001
4	0100	11111	00100
5	0101	01101	00111
6	0110	11001	00111
7	0111	11011	11001
8	1000	00100	00100
9	1001	00100	11111
A	1010	00100	00000
B	1011	00111	00111
C	1100	00111	11001
D	1101	00000	00100
E	1110	00000	11111
F	1111	00000	00000

FIG. 5

(A)



35TS is given at:
(1) the source, or
(2) the sub-network boundary

- Attached by the routing controller
- The TOA represent the instant value of the common time reference 002 when the packet is arrived to the input port

(B) P1/P2, M1 values

P1/P2=00 - CBR - contant bit rate
P1/P2=01 - VBR - variable bit rate
P1/P2=10 - "Best Effort"
P1/P2=11 - Rescheduled data packet

M1=0 - point-to-point packet (one destination)
M1=1 - multicast packet (multiple destination)

FIG. 6

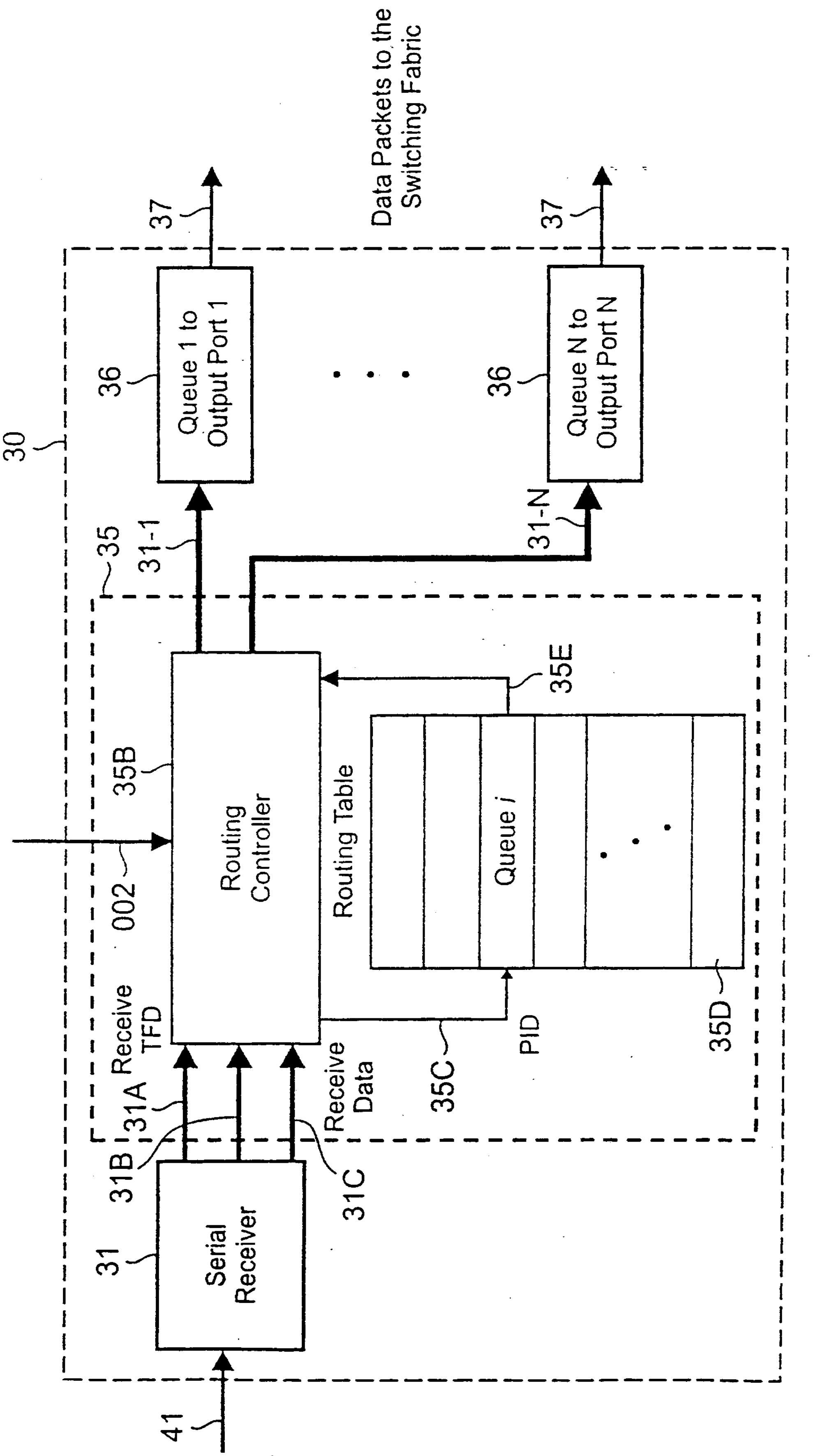

Data Packets to the Switching Fabric
37
37
30
36
Queue 1 to Output Port 1
36
Queue N to Output Port N
35
31-1
31-N
35B
Routing Controller
35E
Routing Table
Queue *i*
002
Receive TFD
Receive Data
31A
31B
31C
35C
PID
35D
31
Serial Receiver
41

FIG. 7

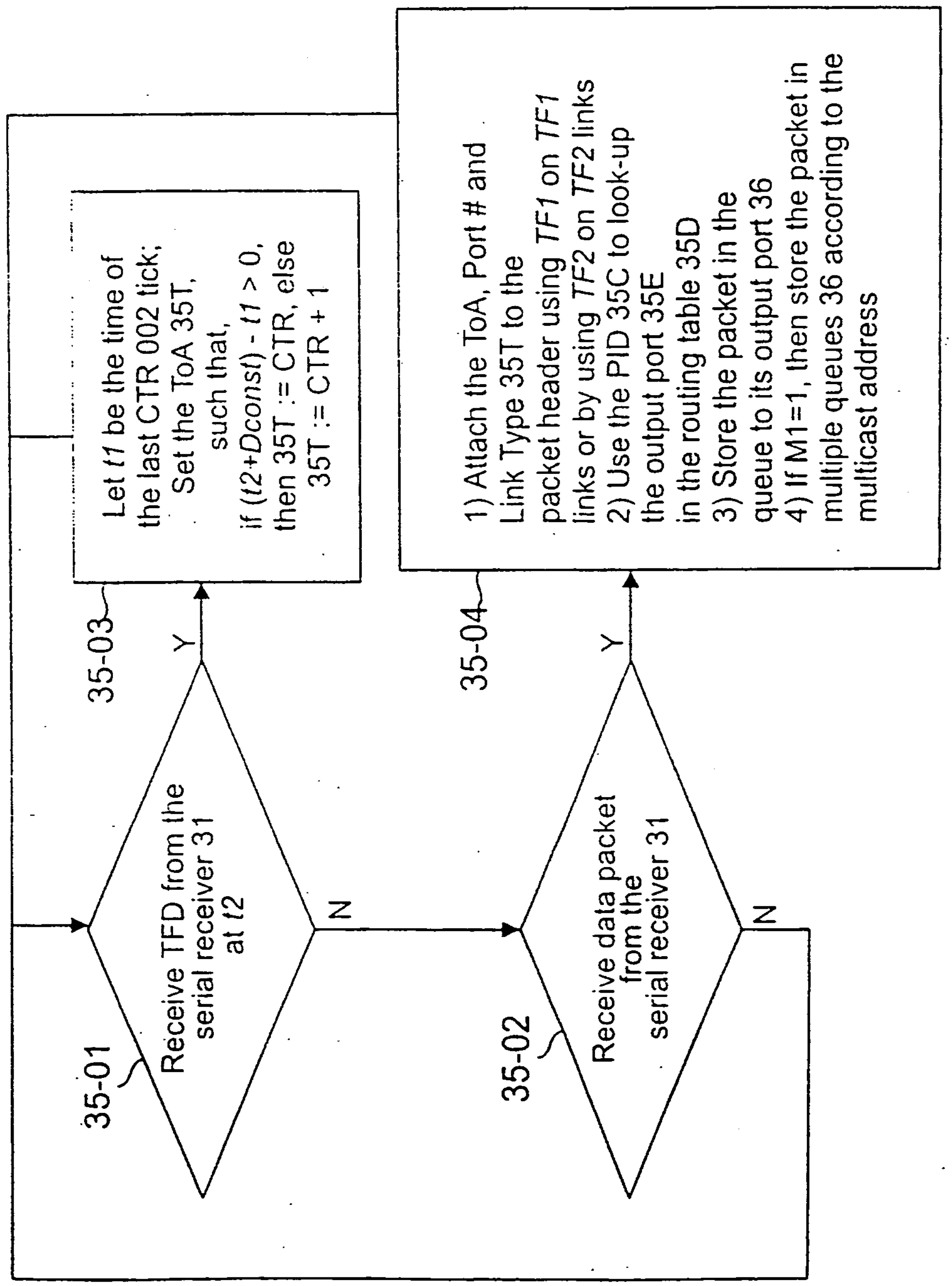

35-01
Receive TFD from the serial receiver 31 at t2
N
Y
35-03
Let t1 be the time of the last CTR 002 tick; Set the ToA 35T, such that, if (t2+Dconst) - t1 > 0, then 35T := CTR, else 35T := CTR + 1
35-02
Receive data packet from the serial receiver 31
N
Y
35-04
1) Attach the ToA, Port # and Link Type 35T to the packet header using TF1 on TF1 links or by using TF2 on TF2 links
2) Use the PID 35C to look-up the output port 35E in the routing table 35D
3) Store the packet in the queue to its output port 36
4) If M1=1, then store the packet in multiple queues 36 according to the multicast address

FIG. 8

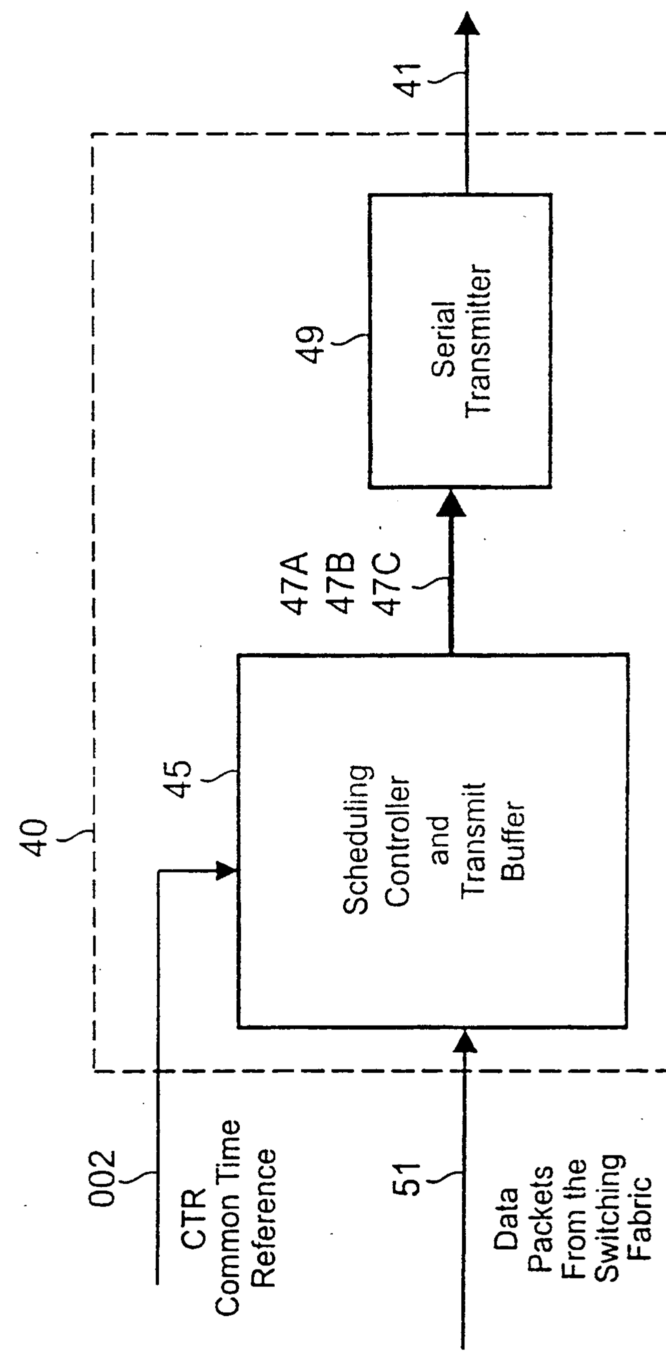

41
49
Serial Transmitter
47A
47B
47C
40
45
Scheduling Controller and Transmit Buffer
002
CTR Common Time Reference
51
Data Packets From the Switching Fabric

FIG. 9

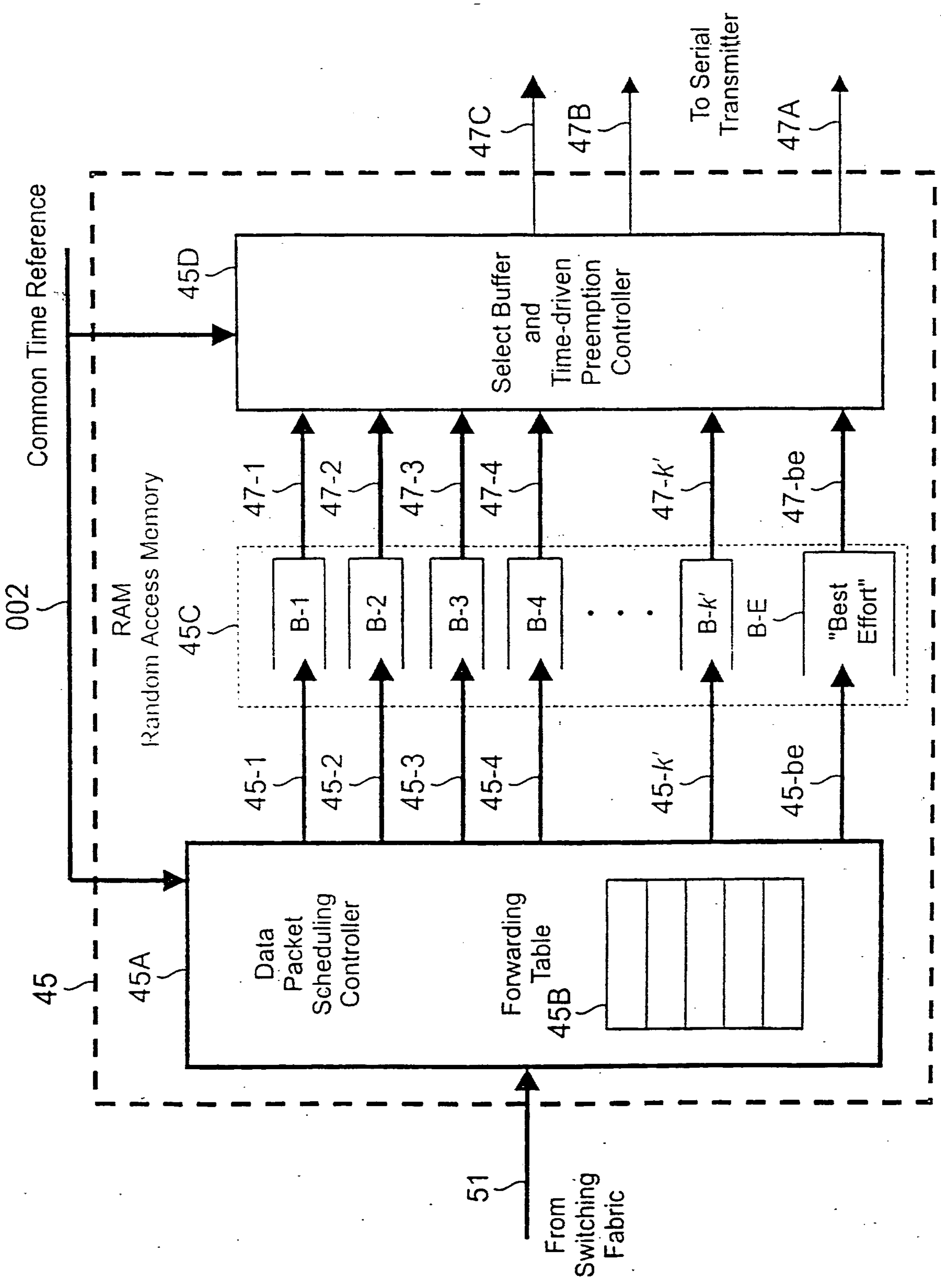

Common Time Reference
002
RAM
Random Access Memory
45C
45
45A
Data
Packet
Scheduling
Controller
Forwarding
Table
45B
45D
Select Buffer
and
Time-driven
Preemption
Controller
45-1
45-2
45-3
45-4
45-k'
45-be
B-1
B-2
B-3
B-4
B-k'
B-E
"Best
Effort"
47-1
47-2
47-3
47-4
47-k'
47-be
47C
47B
47A
To Serial
Transmitter
51
From
Switching
Fabric

FIG. 10

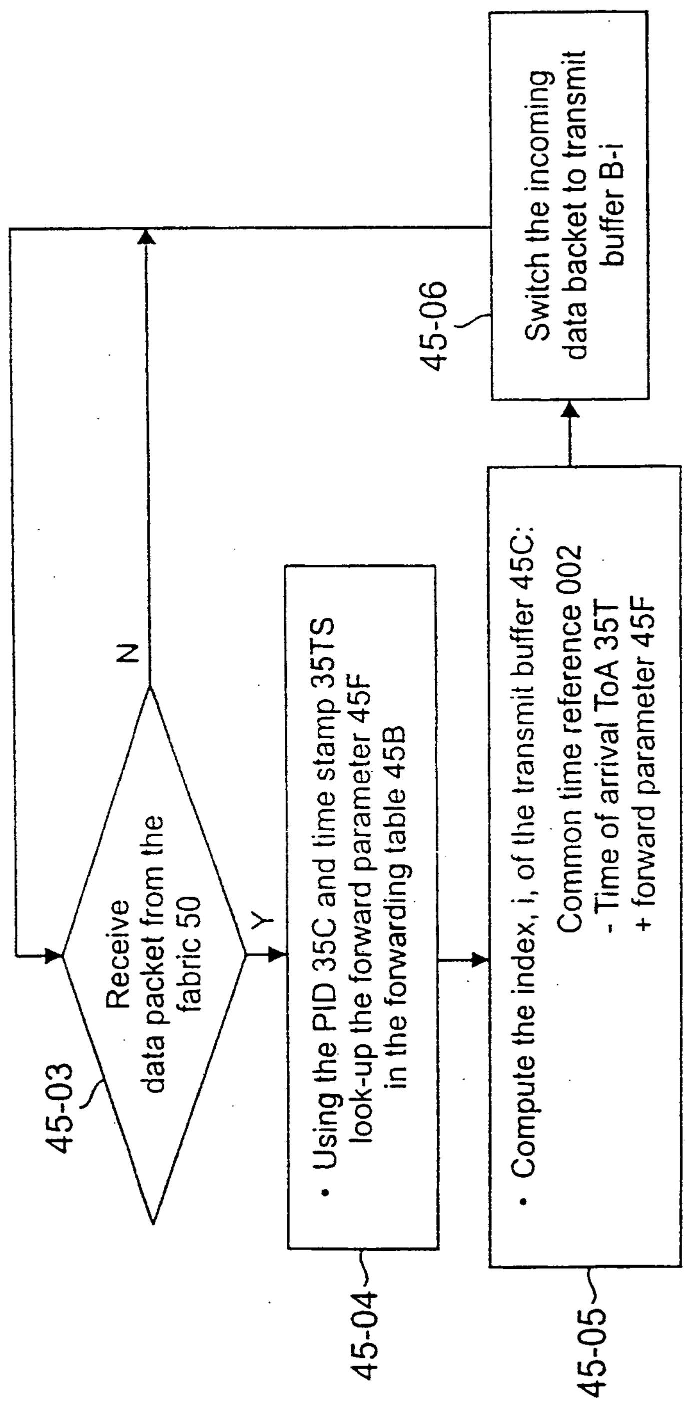

45-03
Receive data packet from the fabric 50
Y
N
45-04
• Using the PID 35C and time stamp 35TS look-up the forward parameter 45F in the forwarding table 45B
45-05
• Compute the index, i, of the transmit buffer 45C:
Common time reference 002
- Time of arrival ToA 35T
+ forward parameter 45F
45-06
Switch the incoming data backet to transmit buffer B-i

FIG. 11

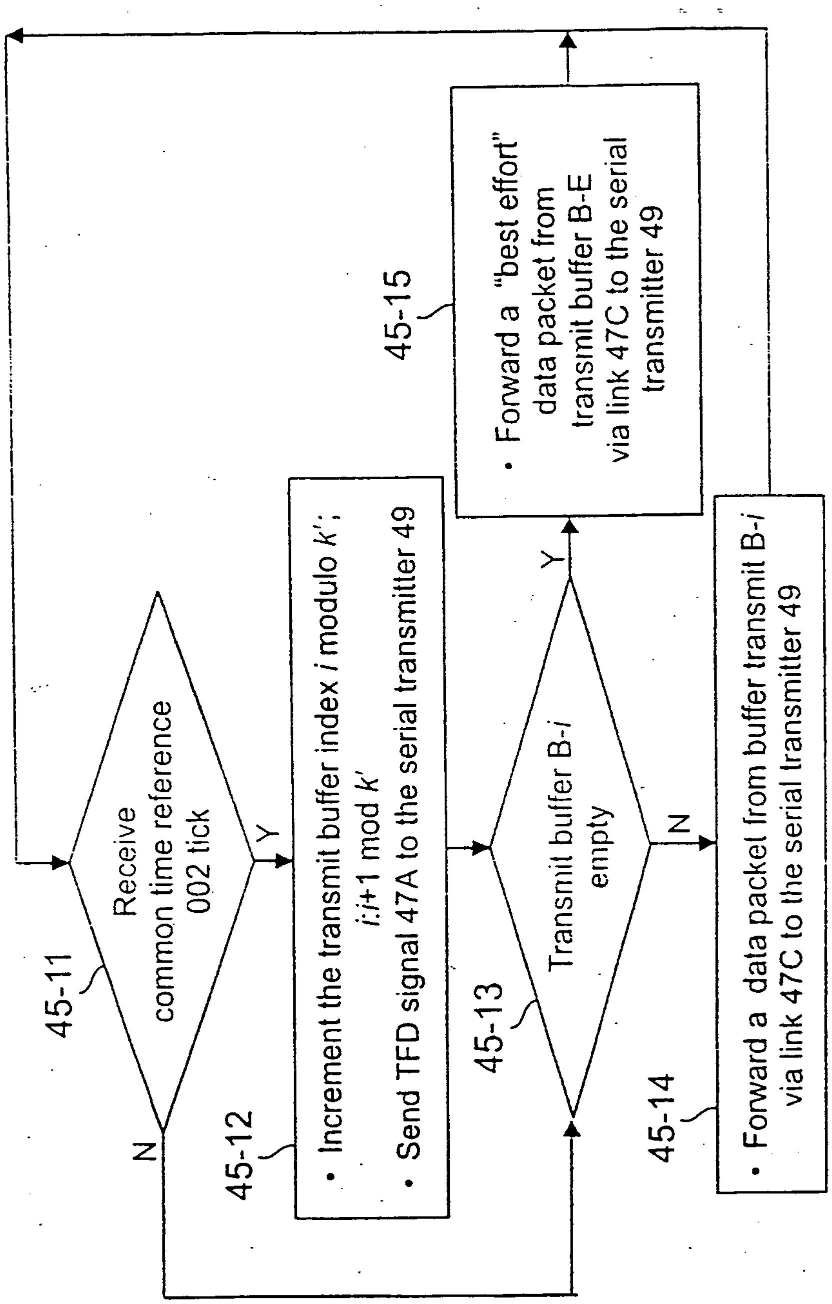

45-11
Receive common time reference 002 tick
Y
N
45-12
• Increment the transmit buffer index *i* modulo *k'*; *i*:*i*+1 mod *k'*
• Send TFD signal 47A to the serial transmitter 49
45-13
Transmit buffer B-*i* empty
Y
N
45-14
• Forward a data packet from buffer transmit B-*i* via link 47C to the serial transmitter 49
45-15
• Forward a "best effort" data packet from transmit buffer B-E via link 47C to the serial transmitter 49

FIG. 12

- Two time intervals:
  - $k1$ * TF1 = 1 UTC second
  - $k2$ * TF2 = 1 UTC second
  - TF2 = ($k1$ / $k2$)* TF1 = k* TF1, where the time cycles of TF1 and TF2 are aligned with respect to UTC, and thus, for k = 2:

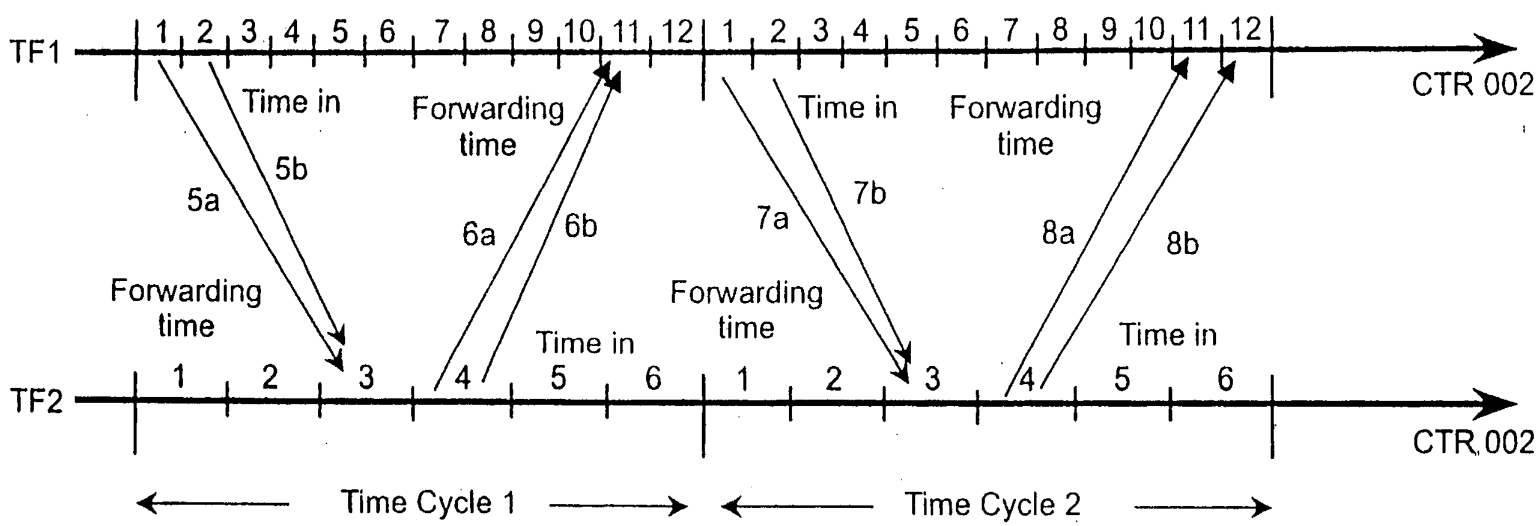


FIG. 13

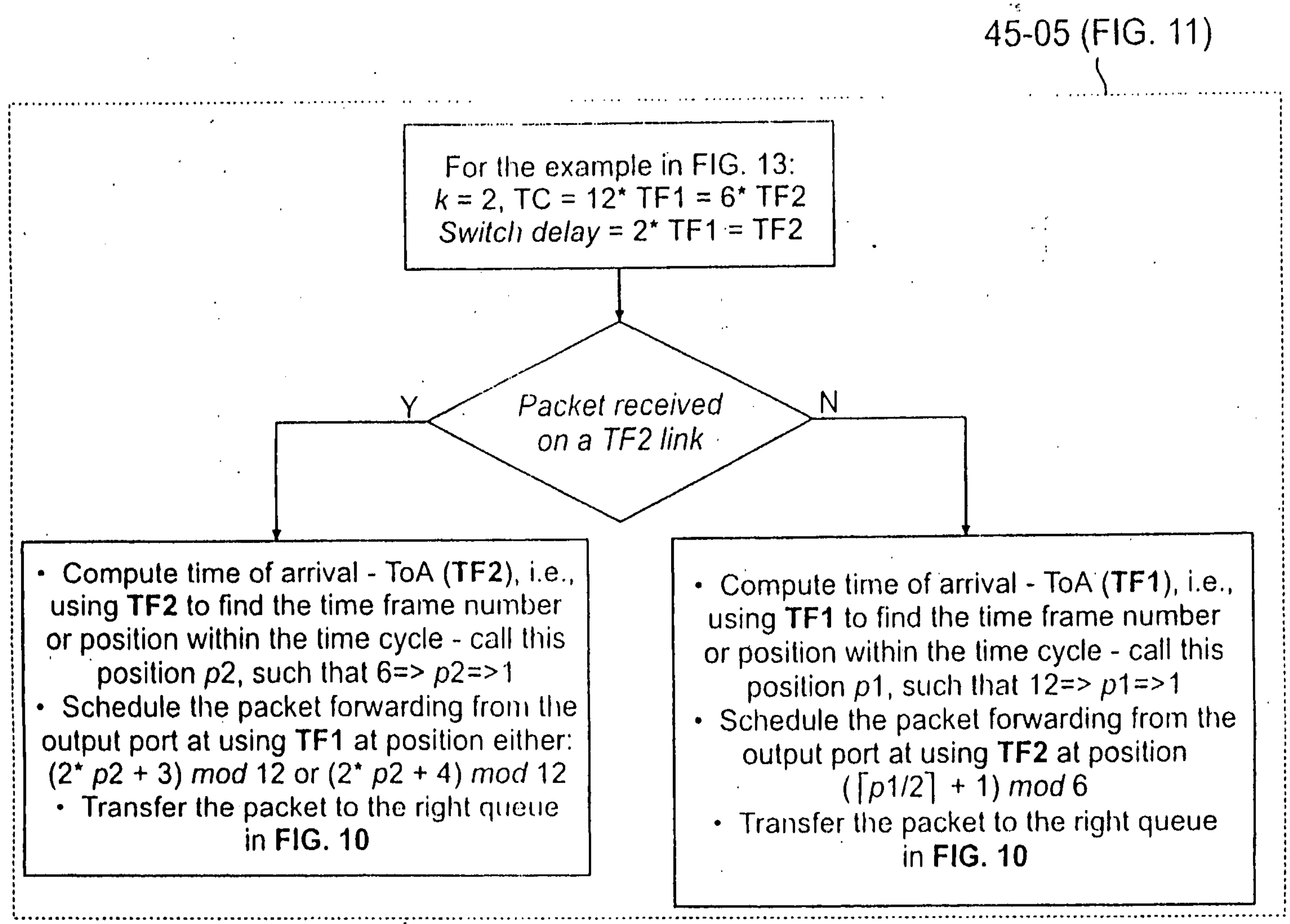

45-05 (FIG. 11)
For the example in FIG. 13:
k = 2, TC = 12* TF1 = 6* TF2
Switch delay = 2* TF1 = TF2
Packet received on a TF2 link
Y
N
• Compute time of arrival - ToA (TF2), i.e., using TF2 to find the time frame number or position within the time cycle - call this position p2, such that 6=> p2=>1
• Schedule the packet forwarding from the output port at using TF1 at position either: (2* p2 + 3) mod 12 or (2* p2 + 4) mod 12
• Transfer the packet to the right queue in FIG. 10
• Compute time of arrival - ToA (TF1), i.e., using TF1 to find the time frame number or position within the time cycle - call this position p1, such that 12=> p1=>1
• Schedule the packet forwarding from the output port at using TF2 at position (⌈p1/2⌉ + 1) mod 6
• Transfer the packet to the right queue in FIG. 10

FIG. 14

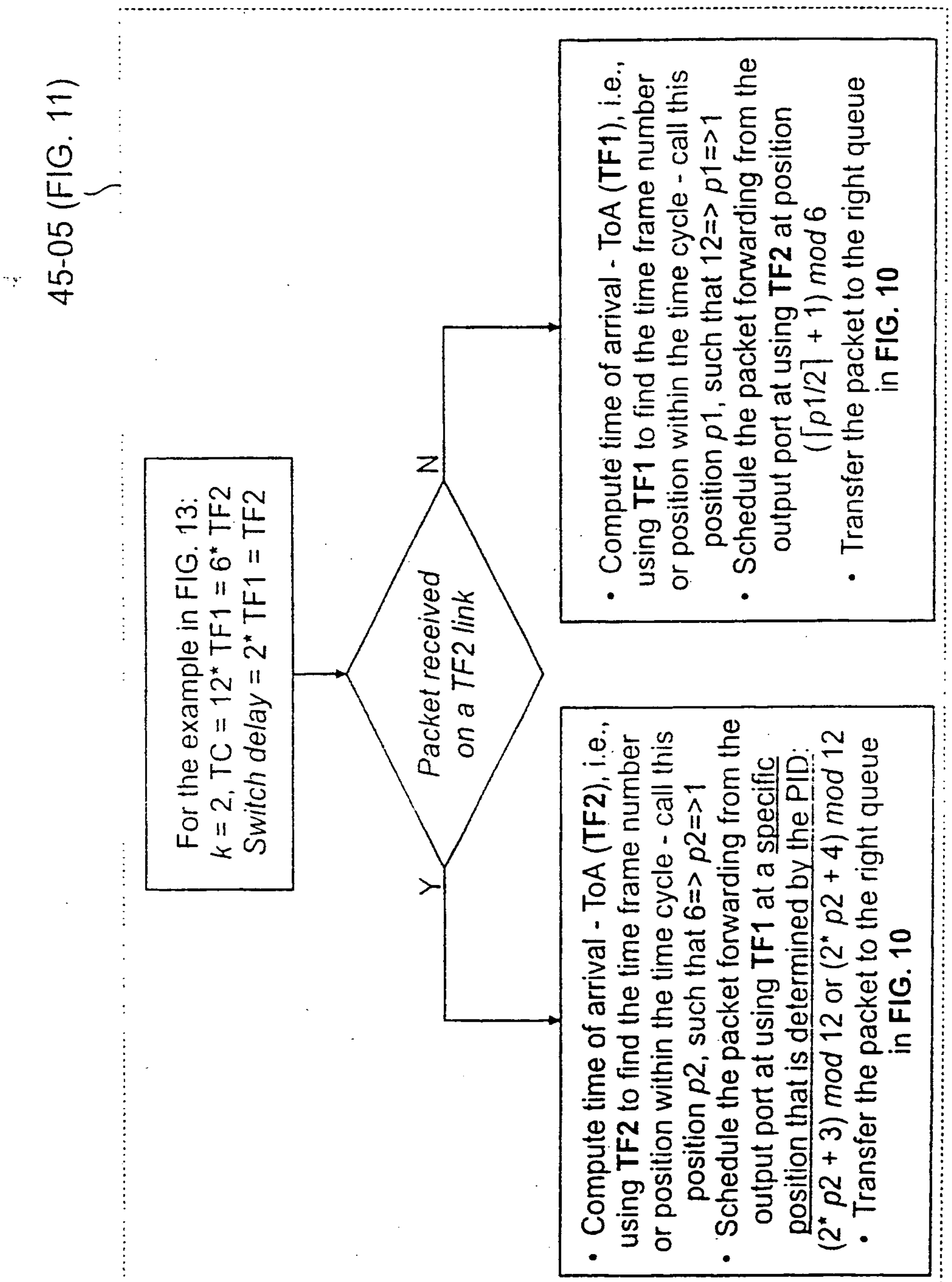
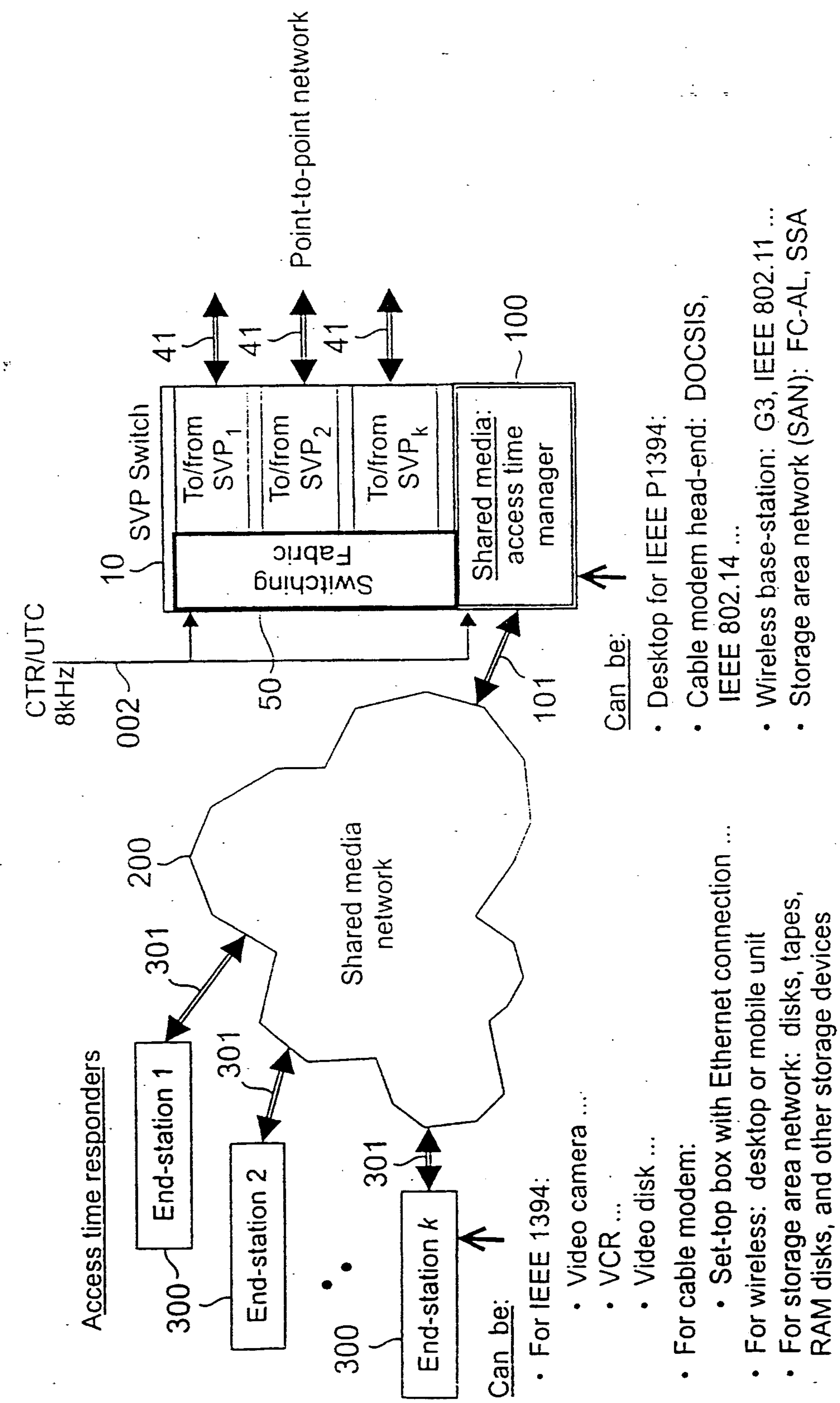

45-05 (FIG. 11)
For the example in FIG. 13:
k = 2, TC = 12* TF1 = 6* TF2
Switch delay = 2* TF1 = TF2
Packet received on a TF2 link
Y
N
• Compute time of arrival - ToA (TF2), i.e., using TF2 to find the time frame number or position within the time cycle - call this position p2, such that 6=> p2=>1
• Schedule the packet forwarding from the output port at using TF1 at a specific position that is determined by the PID: (2* p2 + 3) mod 12 or (2* p2 + 4) mod 12
• Transfer the packet to the right queue in FIG. 10
• Compute time of arrival - ToA (TF1), i.e., using TF1 to find the time frame number or position within the time cycle - call this position p1, such that 12=> p1=>1
• Schedule the packet forwarding from the output port at using TF2 at position (⌈p1/2⌉ + 1) mod 6
• Transfer the packet to the right queue in FIG. 10

FIG. 15



Point-to-point network
41
41
41
100
SVP Switch
To/from SVP$_1$
To/from SVP$_2$
To/from SVP$_k$
Shared media: access time manager
10
Switching Fabric
CTR/UTC 8kHz
002
50
101
Can be:
· Desktop for IEEE P1394:
· Cable modem head-end: DOCSIS, IEEE 802.14 ...
· Wireless base-station: G3, IEEE 802.11 ...
· Storage area network (SAN): FC-AL, SSA
200
Shared media network
301
301
301
Access time responders
End-station 1
End-station 2
End-station k
300
300
Can be:
· For IEEE 1394:
· Video camera ...
· VCR ...
· Video disk ...
· For cable modem:
· Set-top box with Ethernet connection ...
· For wireless: desktop or mobile unit
· For storage area network: disks, tapes, RAM disks, and other storage devices

FIG. 16

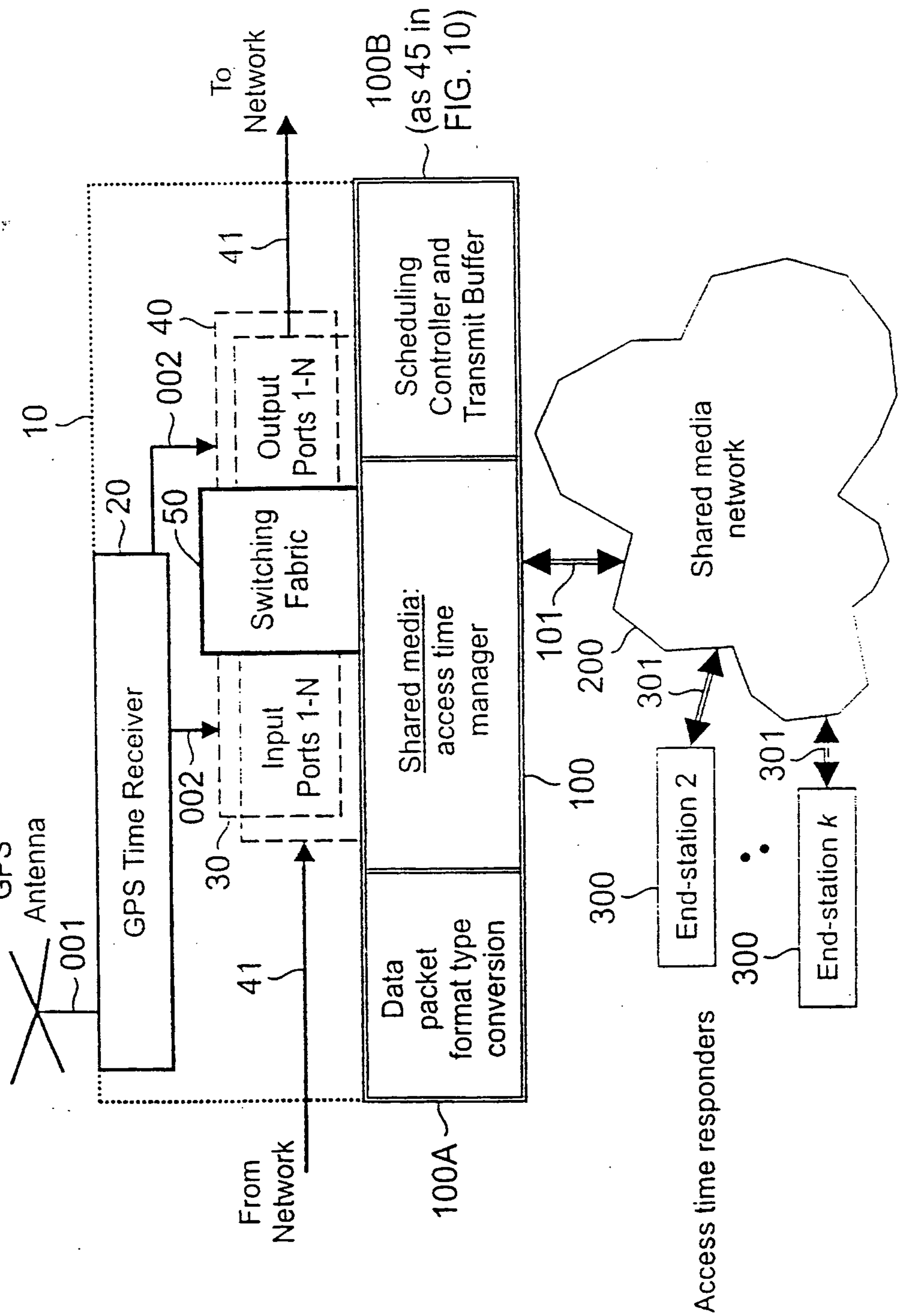

GPS Antenna
001
GPS Time Receiver
20
10
002
30
Input Ports 1-N
50
Switching Fabric
002
40
Output Ports 1-N
41
To Network
41
From Network
100B (as 45 in FIG. 10)
Data packet format type conversion
Shared media: access time manager
Scheduling Controller and Transmit Buffer
100A
100
101
200
Shared media network
301
301
300
End-station 2
300
End-station k
Access time responders

FIG. 17

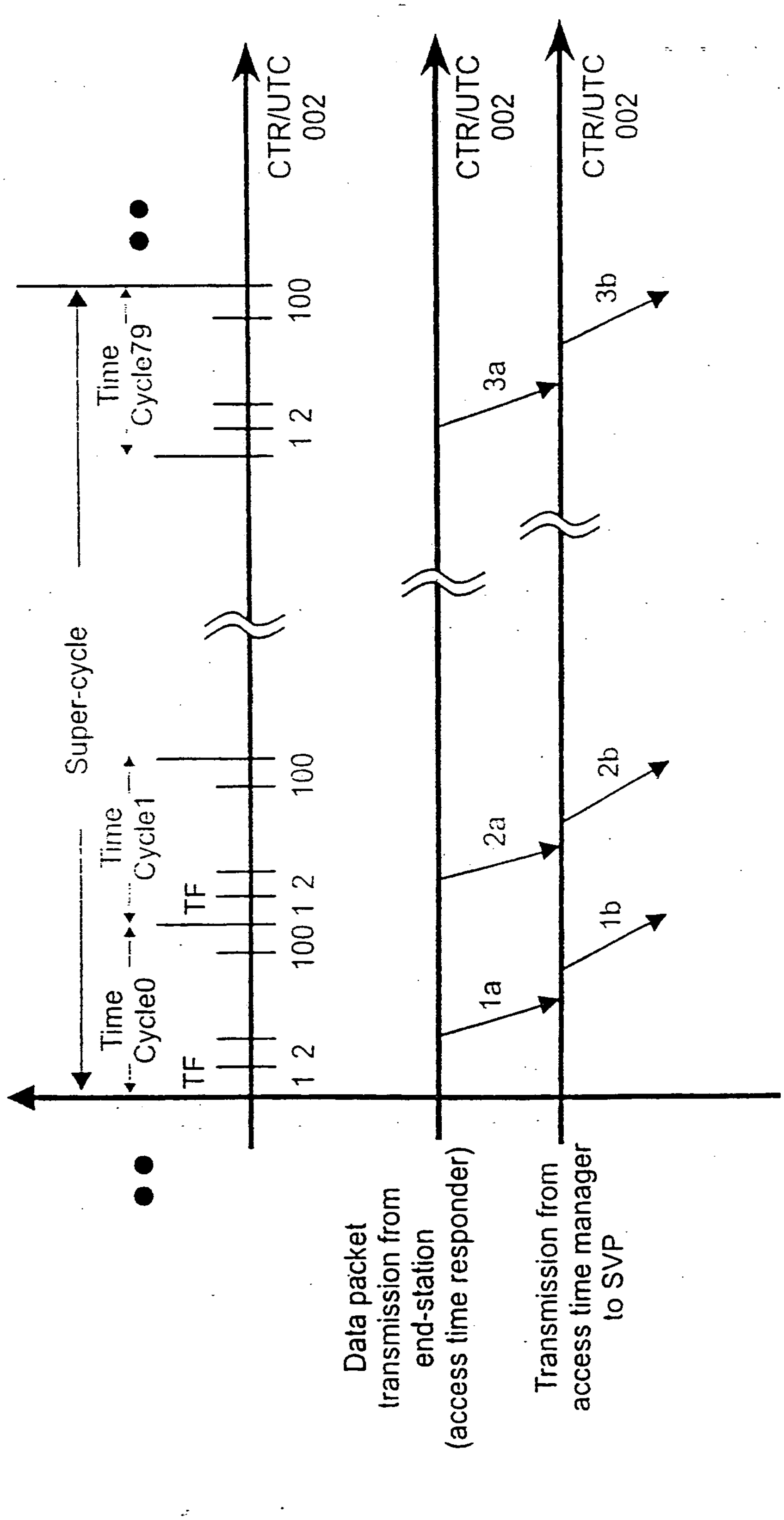

Super-cycle
Time Cycle0
Time Cycle1
Time Cycle79
TF
TF
1 2
100 1 2
100
1 2
100
CTR/UTC 002
CTR/UTC 002
CTR/UTC 002
1a
1b
2a
2b
3a
3b
Data packet transmission from end-station (access time responder)
Transmission from access time manager to SVP

FIG. 18

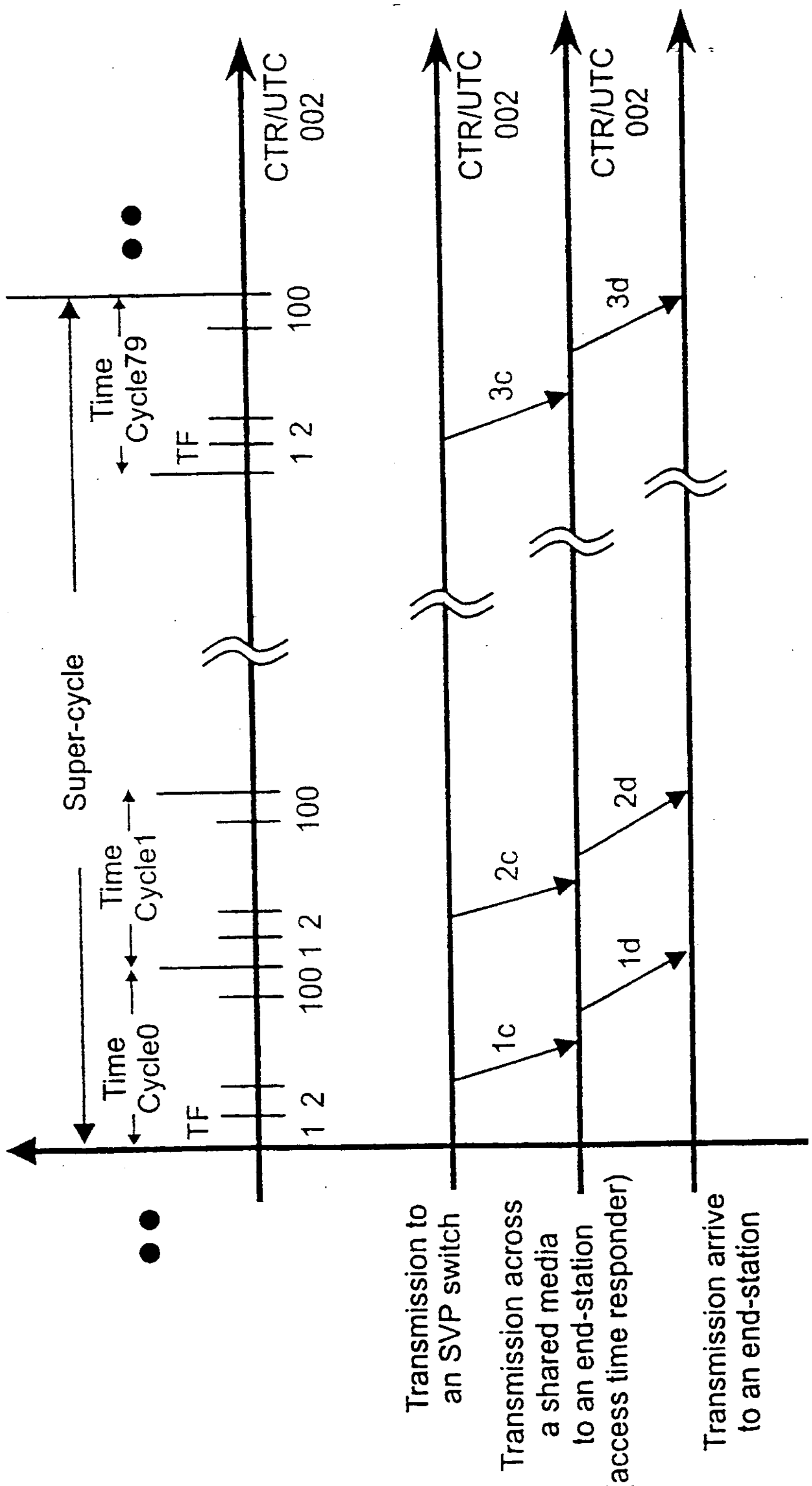

Super-cycle
Time Cycle0
Time Cycle1
Time Cycle79
TF
1 2
100 1 2
100
CTR/UTC 002
1c
1d
2c
2d
3c
3d
Transmission to an SVP switch
Transmission across a shared media to an end-station (access time responder)
Transmission arrive to an end-station

FIG. 19

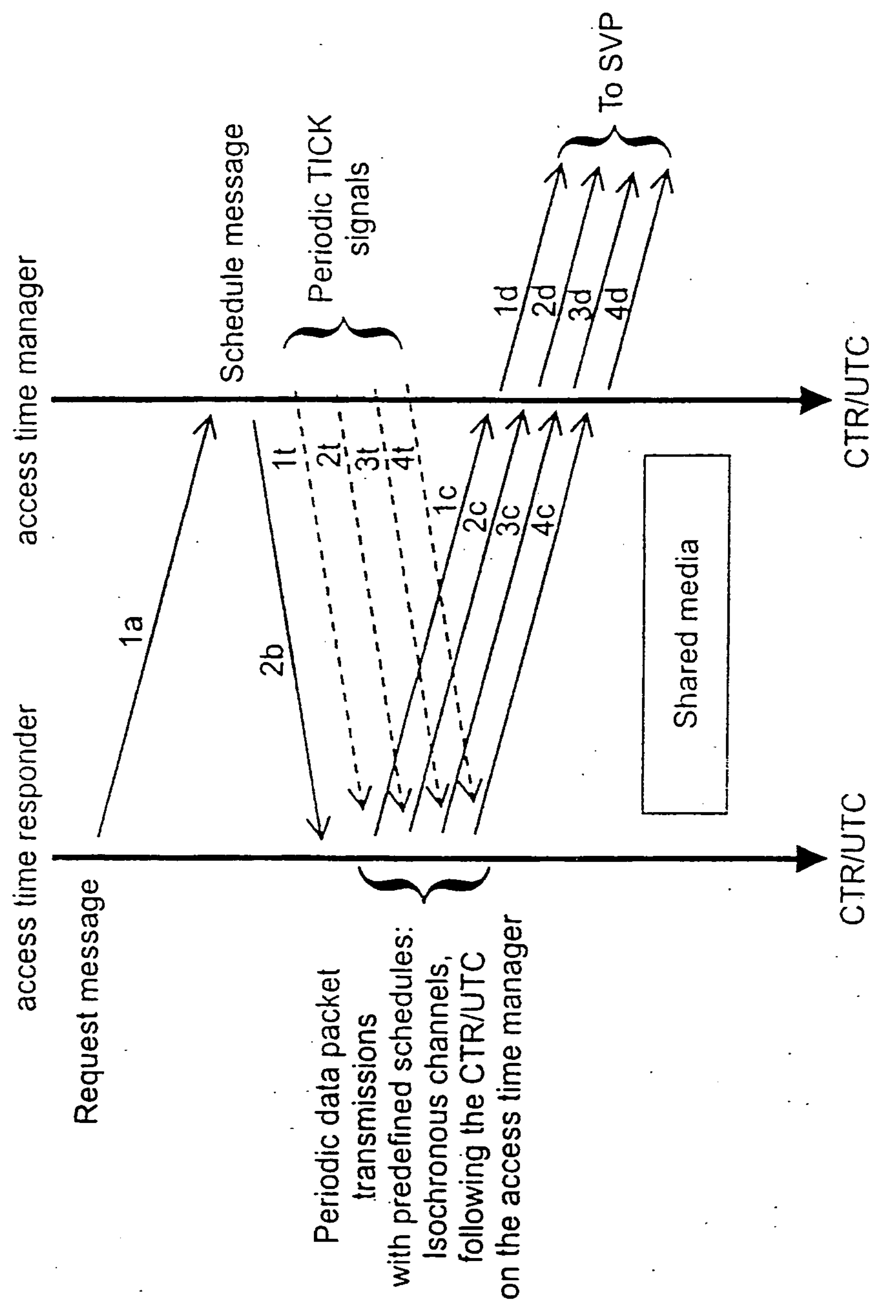

access time responder
access time manager
Request message
1a
Schedule message
2b
Periodic TICK signals
1t
2t
3t
4t
1c
2c
3c
4c
1d
2d
3d
4d
To SVP
Shared media
CTR/UTC
CTR/UTC
Periodic data packet transmissions
with predefined schedules:
Isochronous channels,
following the CTR/UTC
on the access time manager

FIG. 20

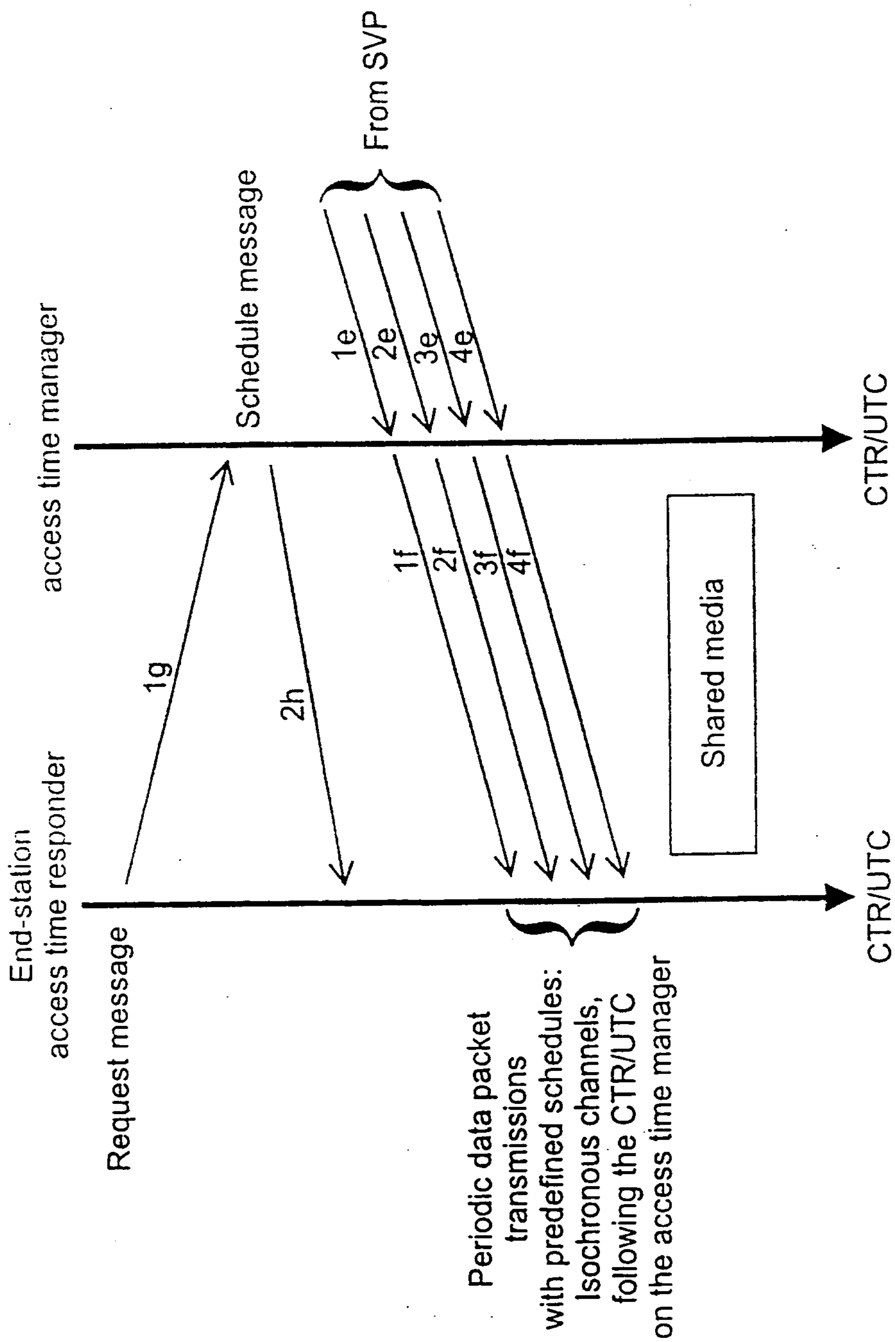

End-station
access time responder
access time manager
Request message
Schedule message
From SVP
1g
2h
1e
2e
3e
4e
1f
2f
3f
4f
Shared media
CTR/UTC
CTR/UTC
Periodic data packet
transmissions
with predefined schedules:
Isochronous channels,
following the CTR/UTC
on the access time manager

FIG. 21

(A) Request message

Sender ID	Device ID	Device type	Resource description	Request Description

(B) Schedule message

Sender ID	Device ID	Device type	Schedule description: (t_1/s_1) (t_2/s_2) (t_3/s_3) ... (t_k/s_k)

t_k - the number of time frame in the time cycle or super cycle for transmission over ther first SVP link

s_k - the number of bytes that can be transmitted in that time frame over the first SVP link

This following set (t_1/s_1) (t_2/s_2) (t_3/s_3) ... (t_k/s_k) can define various schedules including *complex schedule*

FIG. 22

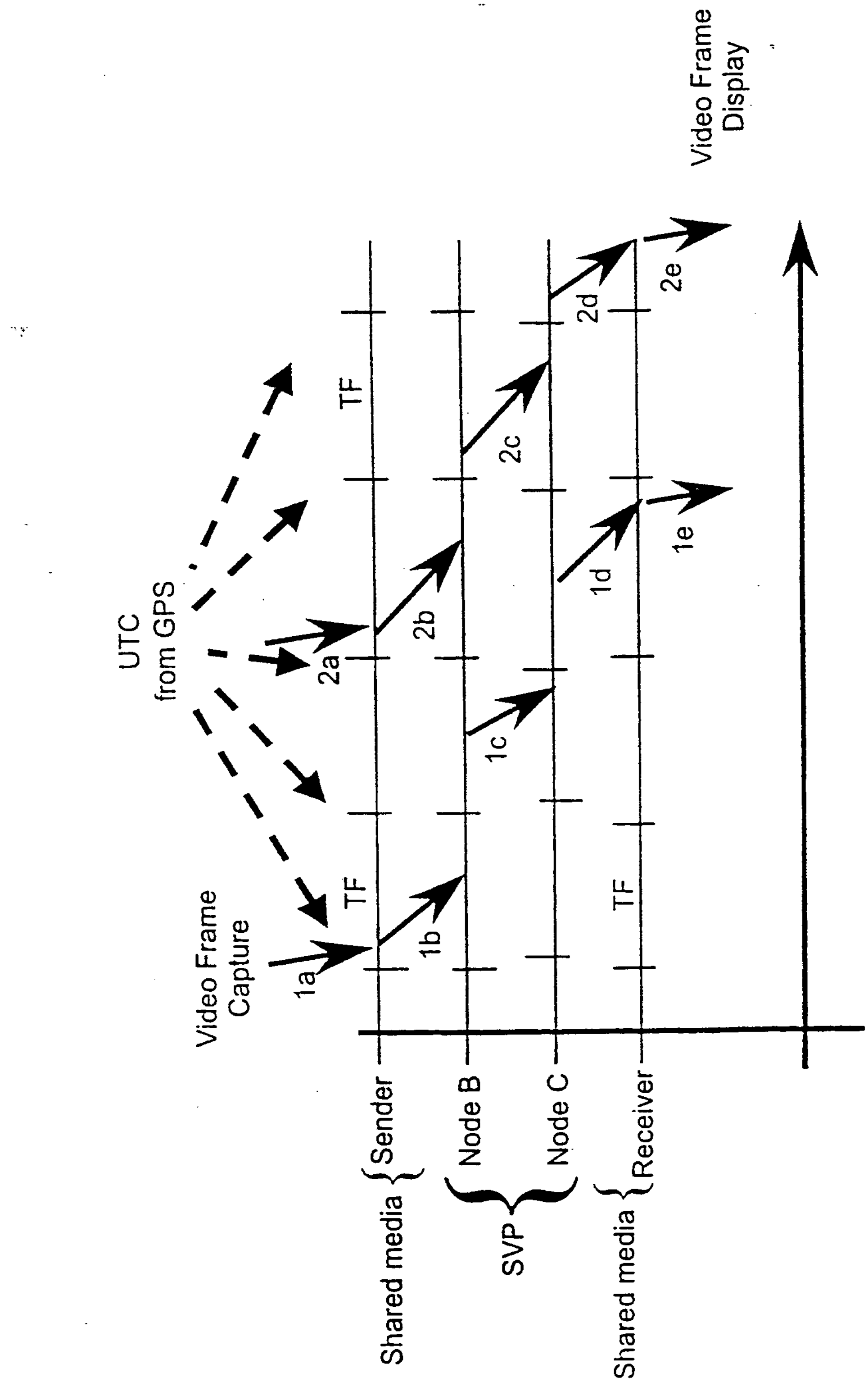

Video Frame Display
UTC from GPS
Video Frame Capture
TF
TF
TF
1a
1b
1c
1d
1e
2a
2b
2c
2d
2e
Sender
Node B
Node C
Receiver
Shared media
SVP
Shared media

FIG. 23

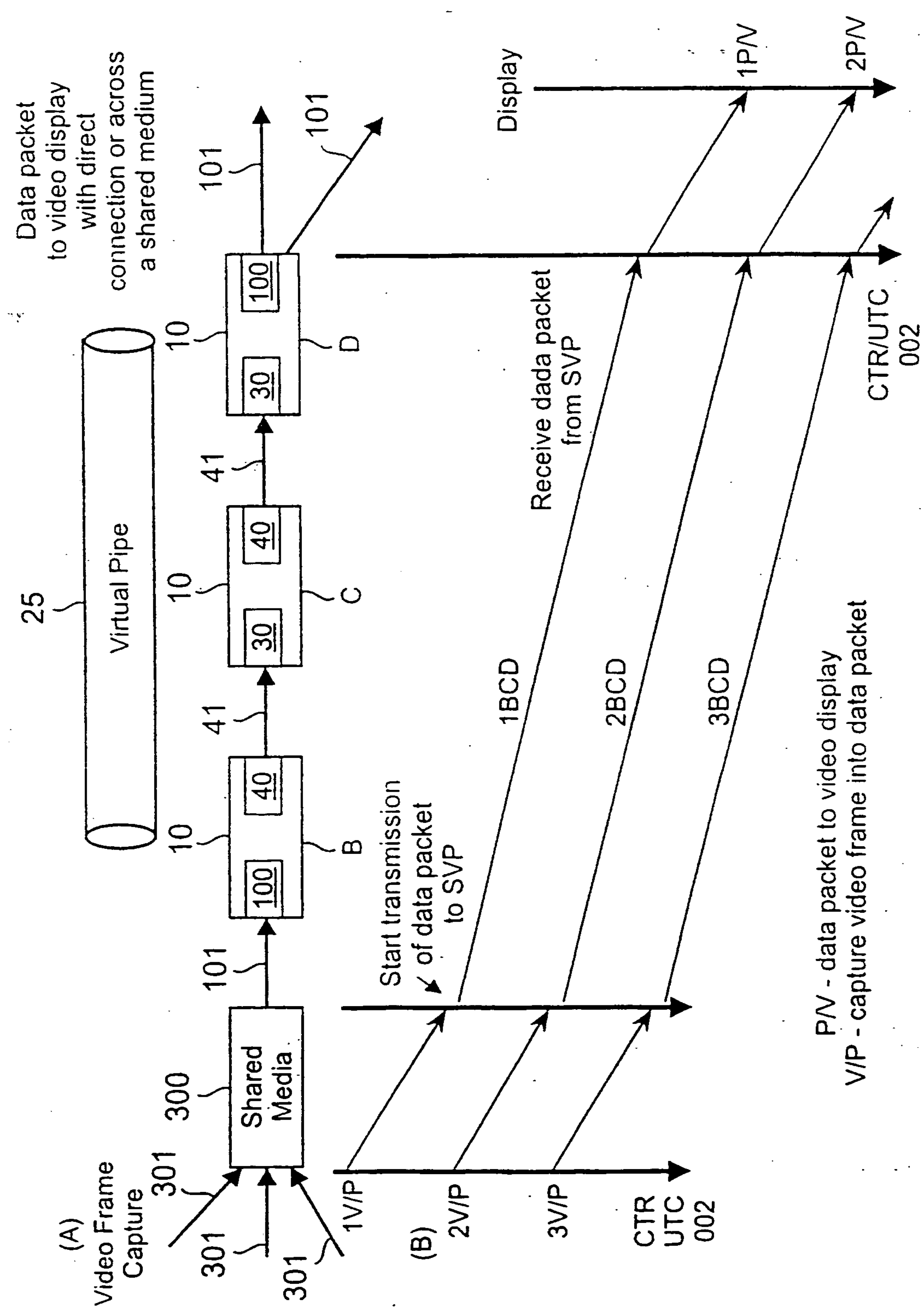

Data packet
to video display
with direct
connection or across
a shared medium
25
Virtual Pipe
101
101
10
10
10
100
40
41
30
40
41
30
100
B
C
D
(A)
Video Frame
Capture
301
301
301
300
Shared
Media
101
(B)
1V/P
2V/P
3V/P
CTR
UTC
002
Start transmission
of data packet
to SVP
1BCD
2BCD
3BCD
Receive dada packet
from SVP
CTR/UTC
002
Display
1P/V
2P/V
P/V - data packet to video display
V/P - capture video frame into data packet

FIG. 24

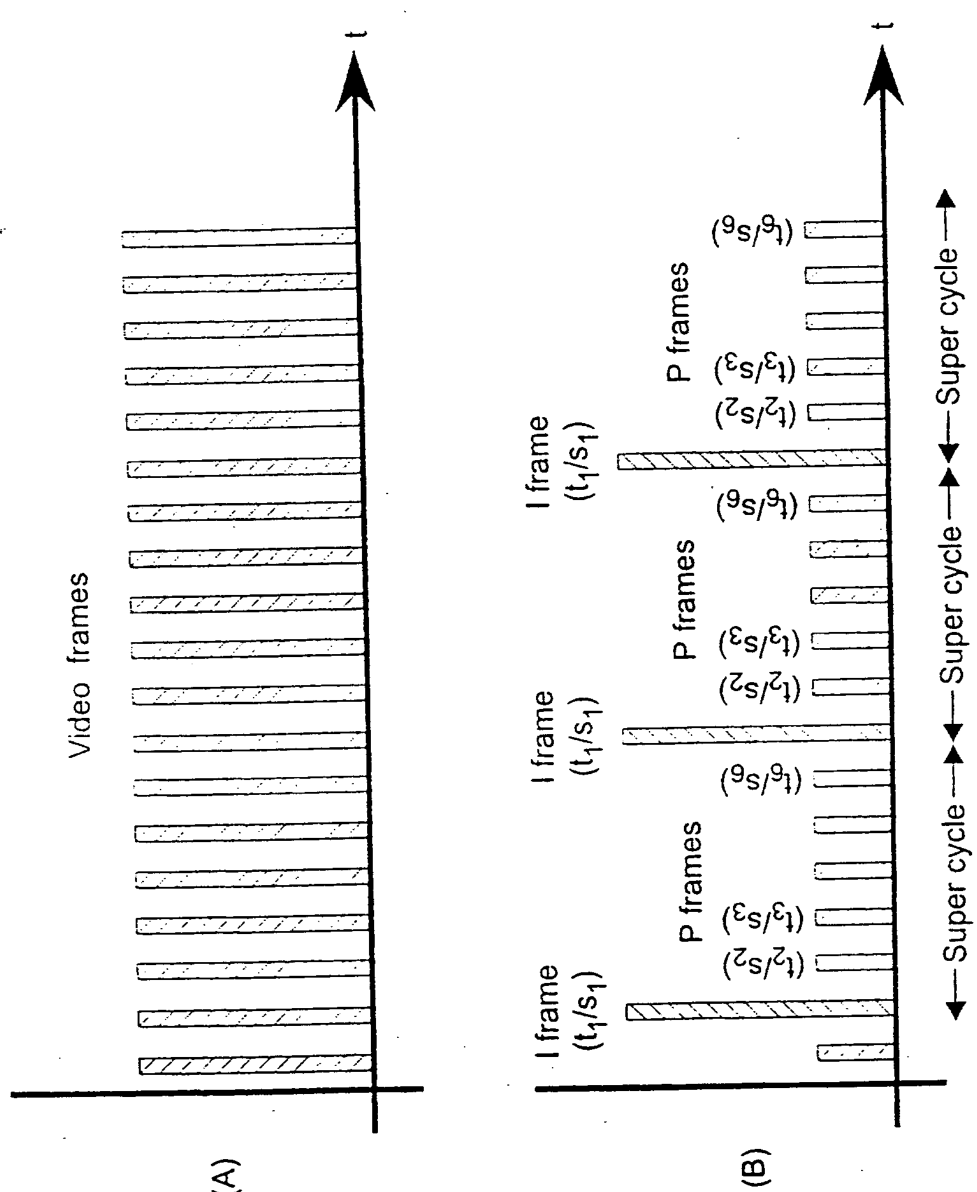

Video frames
t
(A)
I frame
(t_1/s_1)
P frames
(t_2/s_2)
(t_3/s_3)
(t_6/s_6)
Super cycle
(B)

FIG. 25

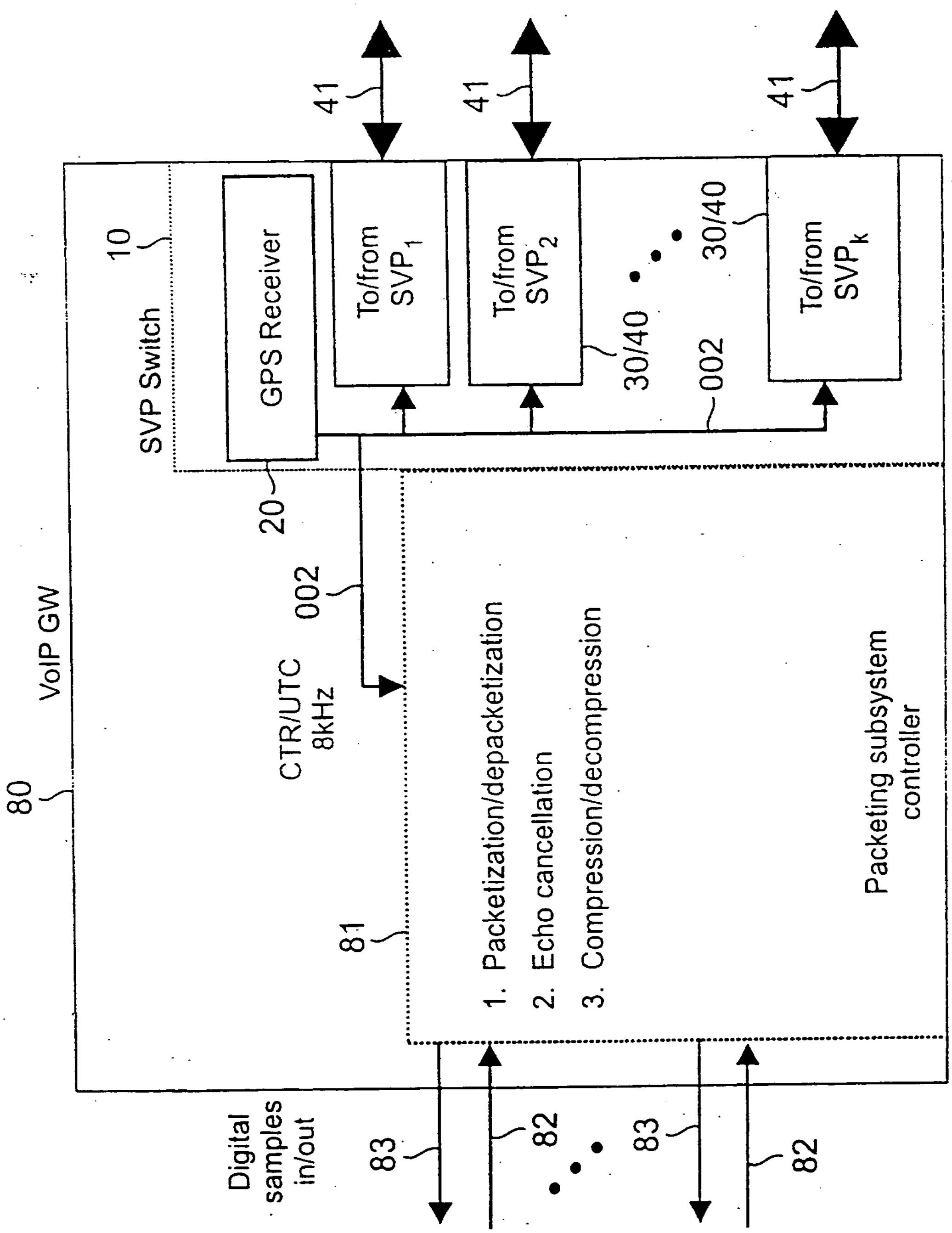

VoIP GW
80
SVP Switch
10
GPS Receiver
20
To/from SVP$_1$
To/from SVP$_2$
To/from SVP$_k$
41
41
41
30/40
30/40
002
002
CTR/UTC
8kHz
81
1. Packetization/depacketization
2. Echo cancellation
3. Compression/decompression
Packeting subsystem controller
Digital samples in/out
83
82
83
82

FIG. 26

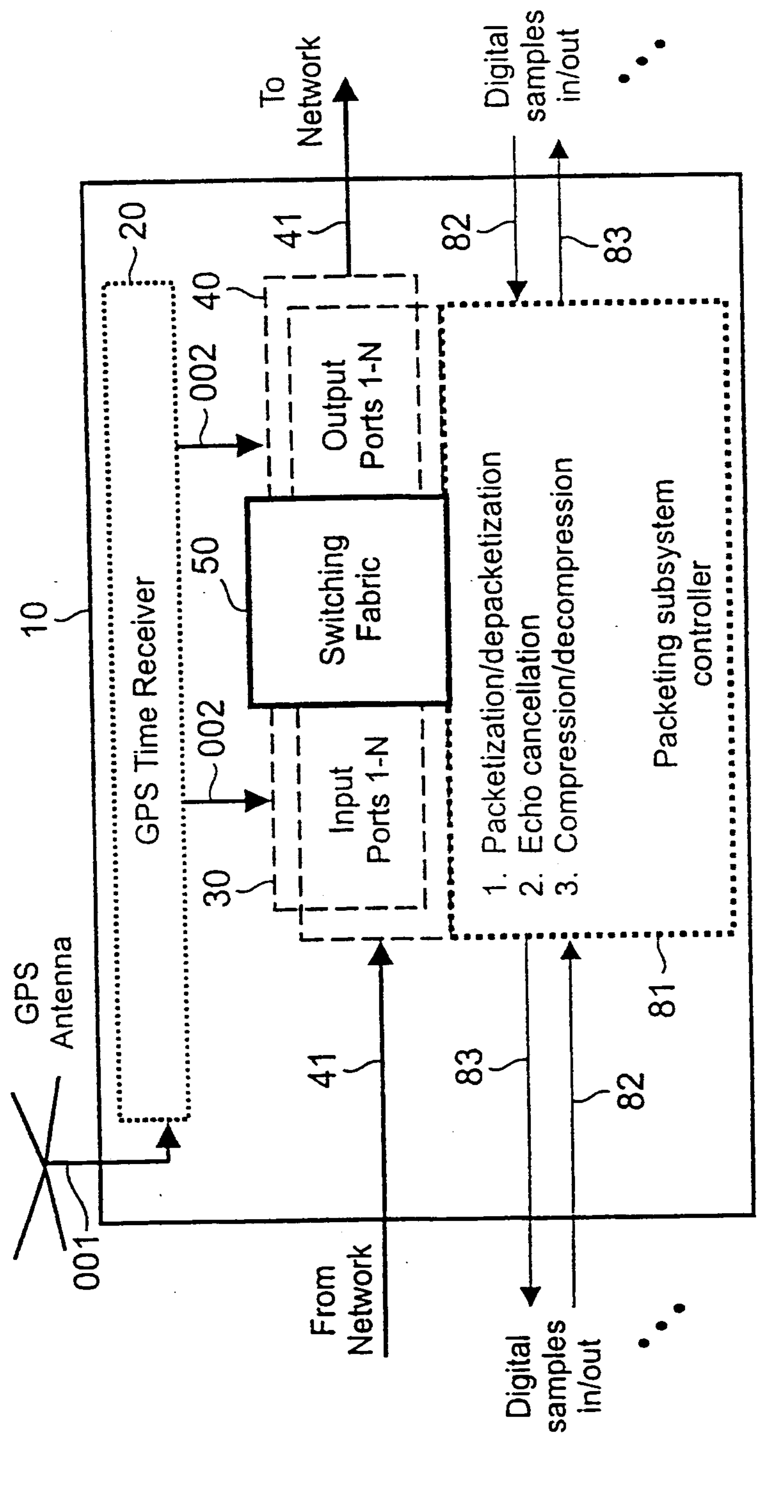

To Network
Digital samples in/out
GPS Antenna
001
10
20
GPS Time Receiver
002
002
30
Input Ports 1-N
50
Switching Fabric
40
Output Ports 1-N
41
41
82
83
83
82
81
1. Packetization/depacketization
2. Echo cancellation
3. Compression/decompression
Packeting subsystem controller
From Network
Digital samples in/out

FIG. 27

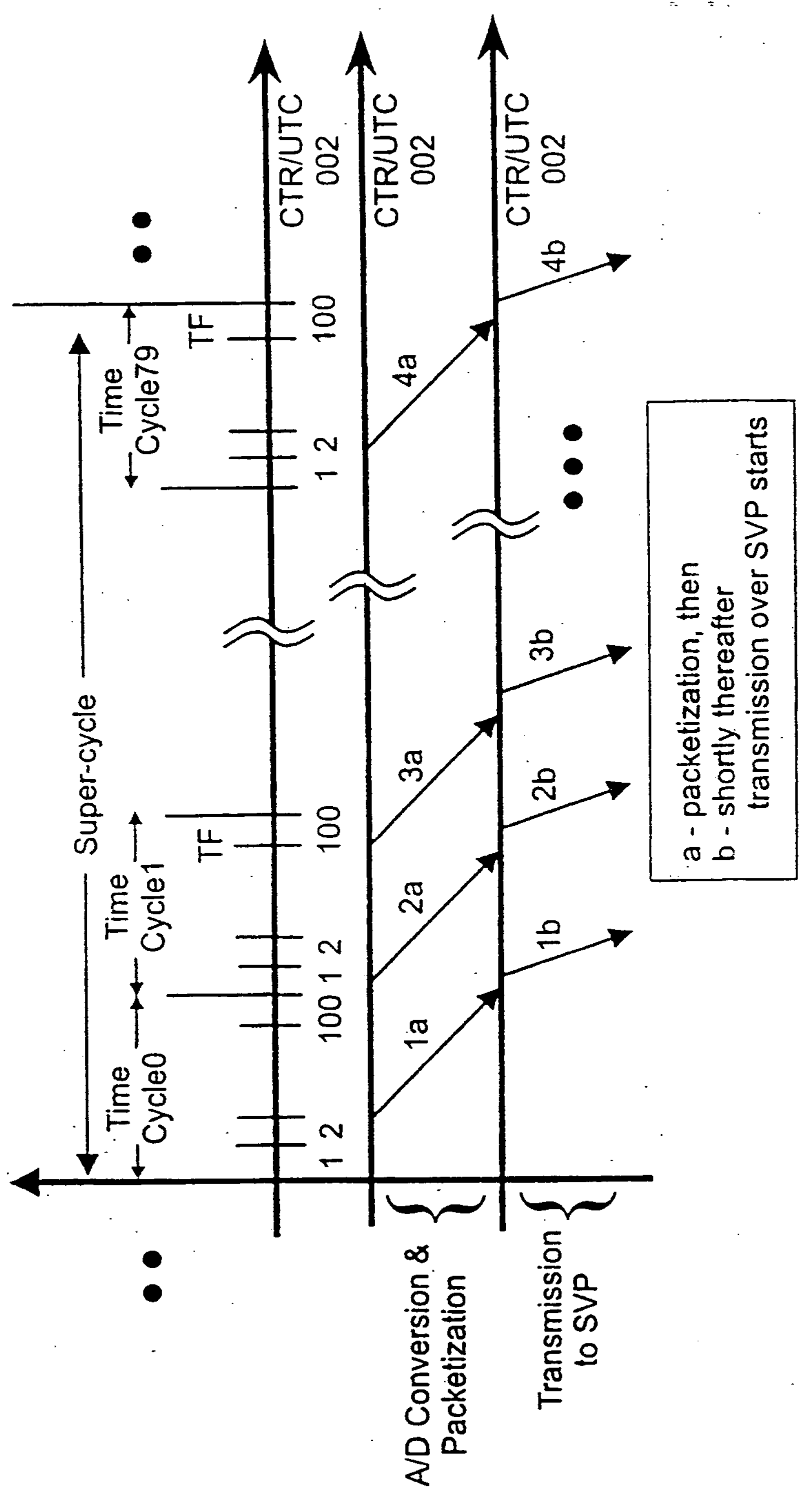

Super-cycle
Time Cycle0
Time Cycle1
Time Cycle79
TF
TF
1 2
100 1 2
100
1 2
100
CTR/UTC 002
CTR/UTC 002
CTR/UTC 002
1a
1b
2a
2b
3a
3b
4a
4b
A/D Conversion & Packetization
Transmission to SVP
a - packetization, then
b - shortly thereafter transmission over SVP starts

FIG. 28

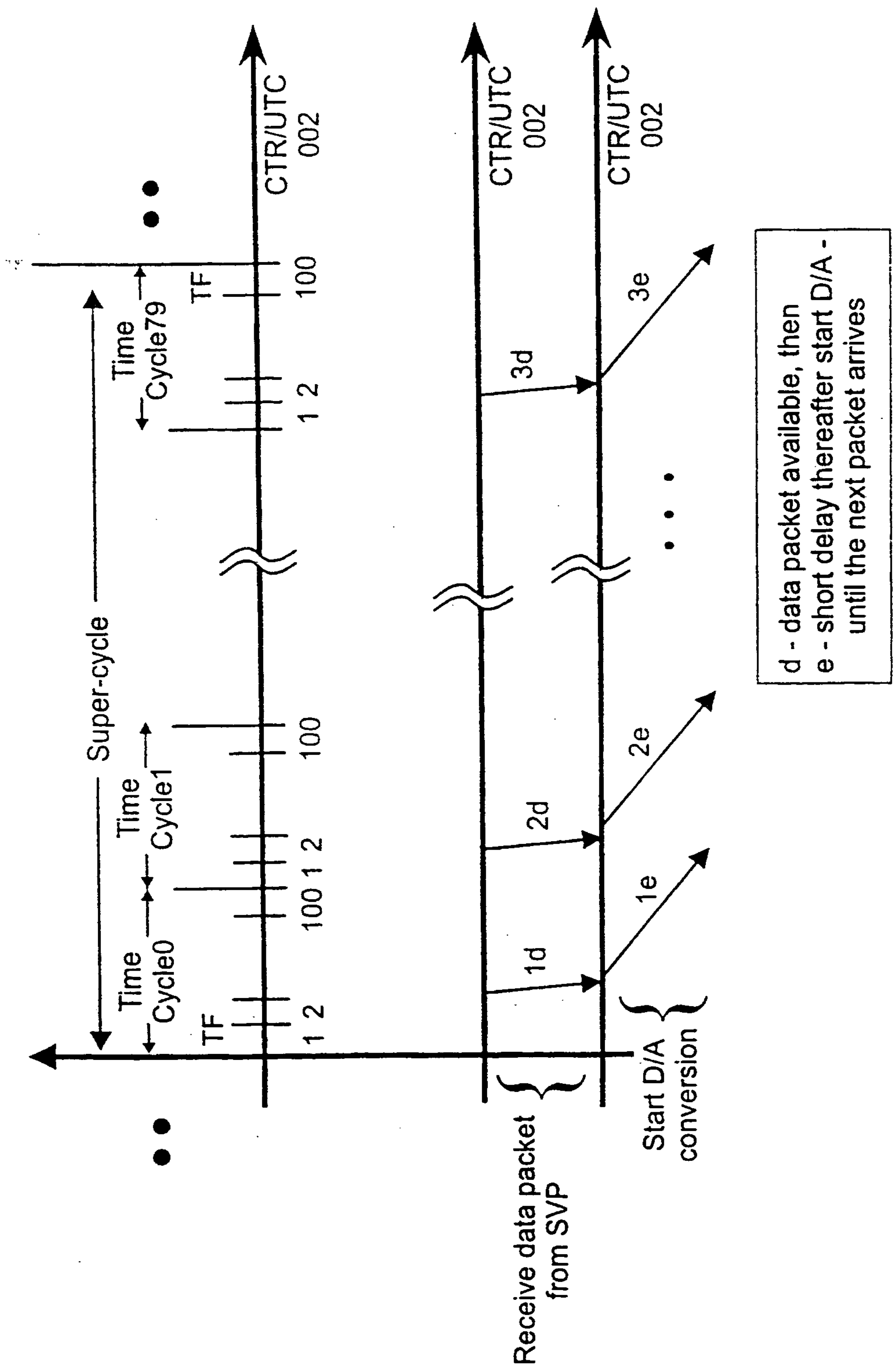

CTR/UTC 002
CTR/UTC 002
CTR/UTC 002
Super-cycle
Time Cycle0
Time Cycle1
Time Cycle79
TF
TF
1 2
100 1 2
100
1 2
100
1d
2d
3d
1e
2e
3e
Receive data packet from SVP
Start D/A conversion
d - data packet available, then
e - short delay thereafter start D/A -
until the next packet arrives

FIG. 29

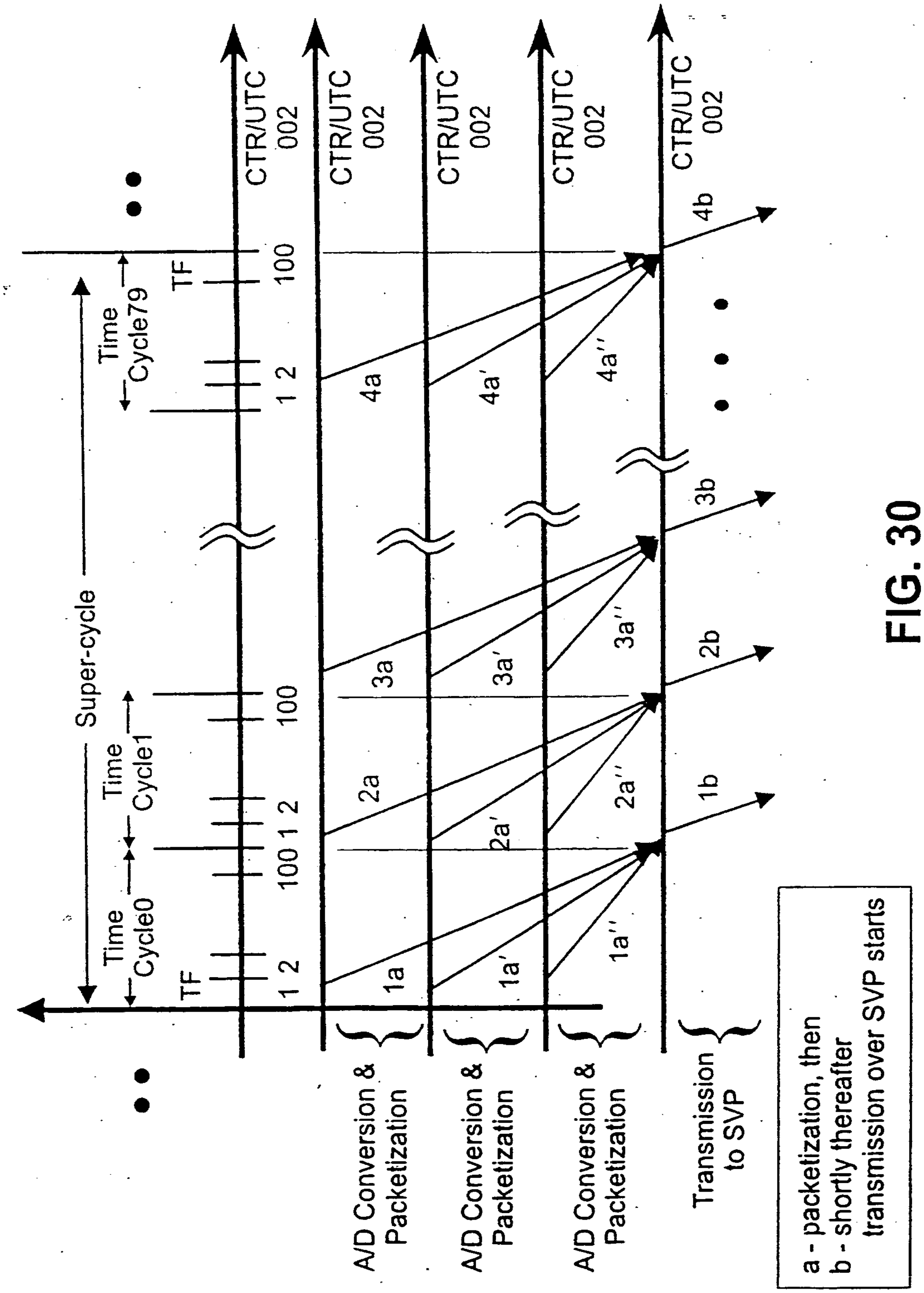

Super-cycle
Time Cycle0
Time Cycle1
Time Cycle79
TF
1 2
100
CTR/UTC 002
A/D Conversion & Packetization
Transmission to SVP
1a
1a'
1a''
1b
2a
2a'
2a''
2b
3a
3a'
3a''
3b
4a
4a'
4a''
4b
a - packetization, then
b - shortly thereafter transmission over SVP starts

FIG. 30

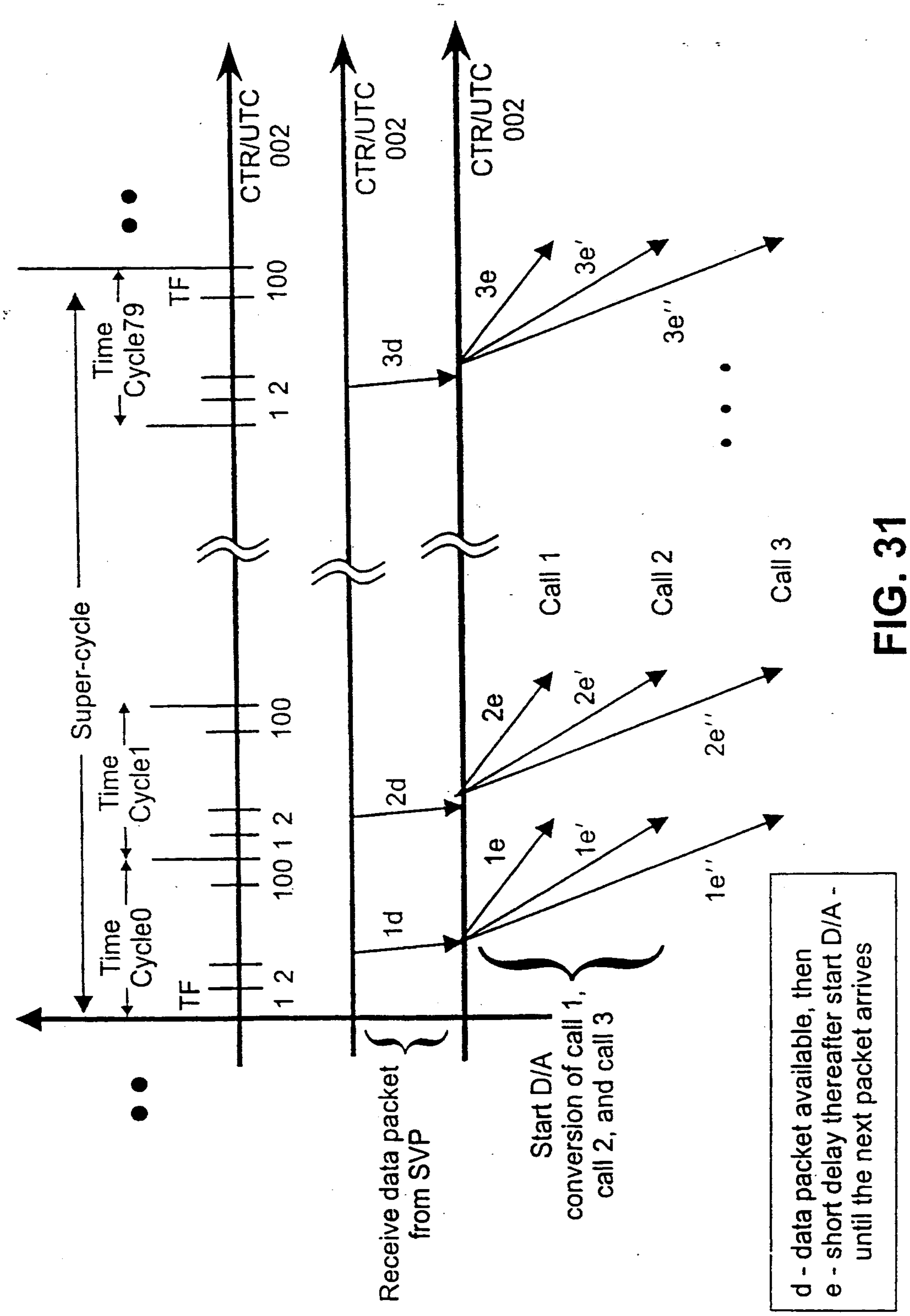

Super-cycle
Time Cycle0
Time Cycle1
Time Cycle79
TF
1 2
100 1 2
100
CTR/UTC 002
Receive data packet from SVP
Start D/A conversion of call 1, call 2, and call 3
1d
2d
3d
1e
1e'
1e''
2e
2e'
2e''
3e
3e'
3e''
Call 1
Call 2
Call 3
d - data packet available, then
e - short delay thereafter start D/A - until the next packet arrives

FIG. 31

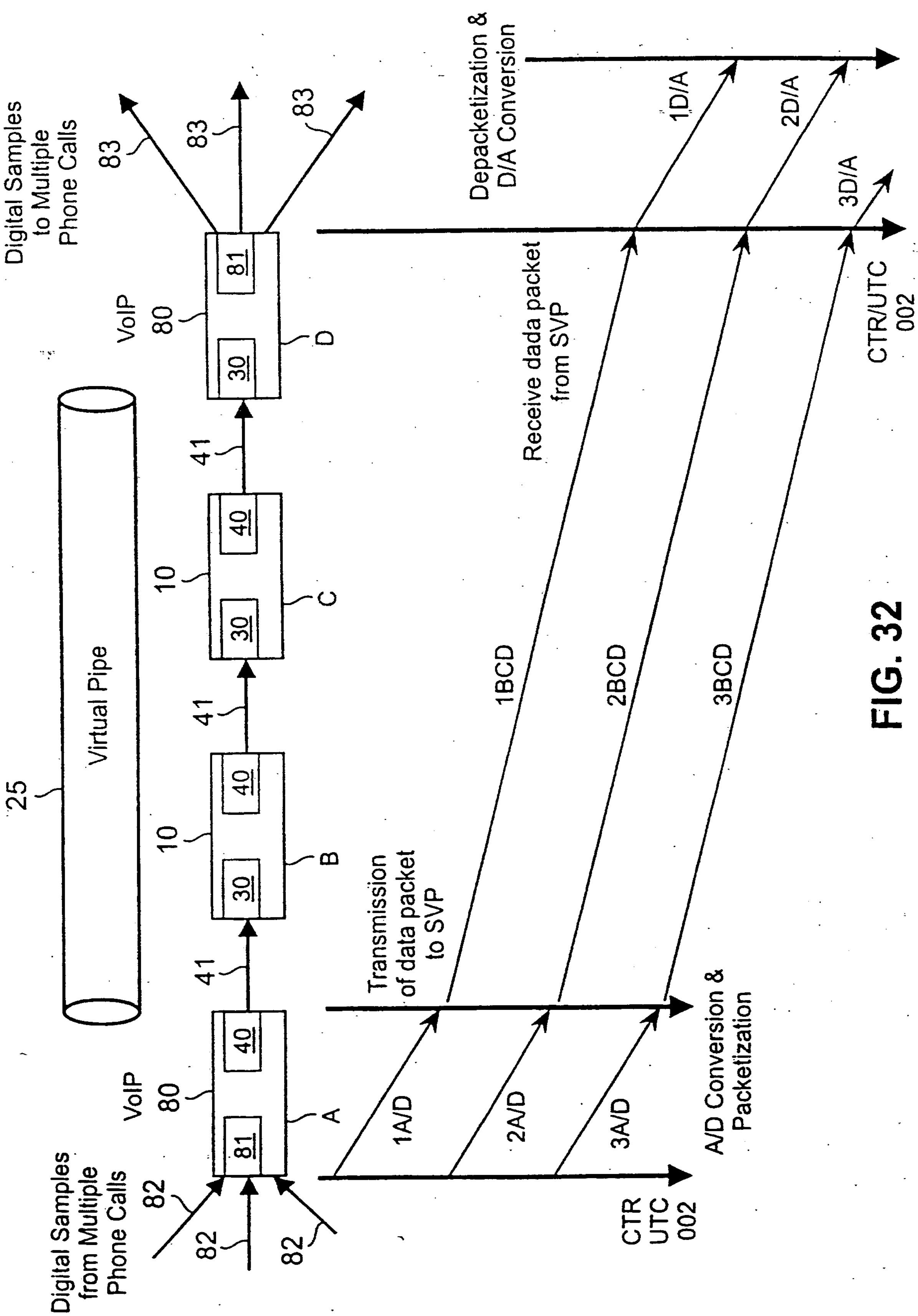

Digital Samples from Multiple Phone Calls
82
82
82
VoIP
80
81
40
A
41
10
30
40
B
41
10
30
40
C
41
VoIP
80
30
81
D
Digital Samples to Multiple Phone Calls
83
83
83
25
Virtual Pipe
CTR
UTC
002
1A/D
2A/D
3A/D
A/D Conversion & Packetization
Transmission of data packet to SVP
1BCD
2BCD
3BCD
Receive dada packet from SVP
CTR/UTC
002
1D/A
2D/A
3D/A
Depacketization & D/A Conversion

FIG. 32

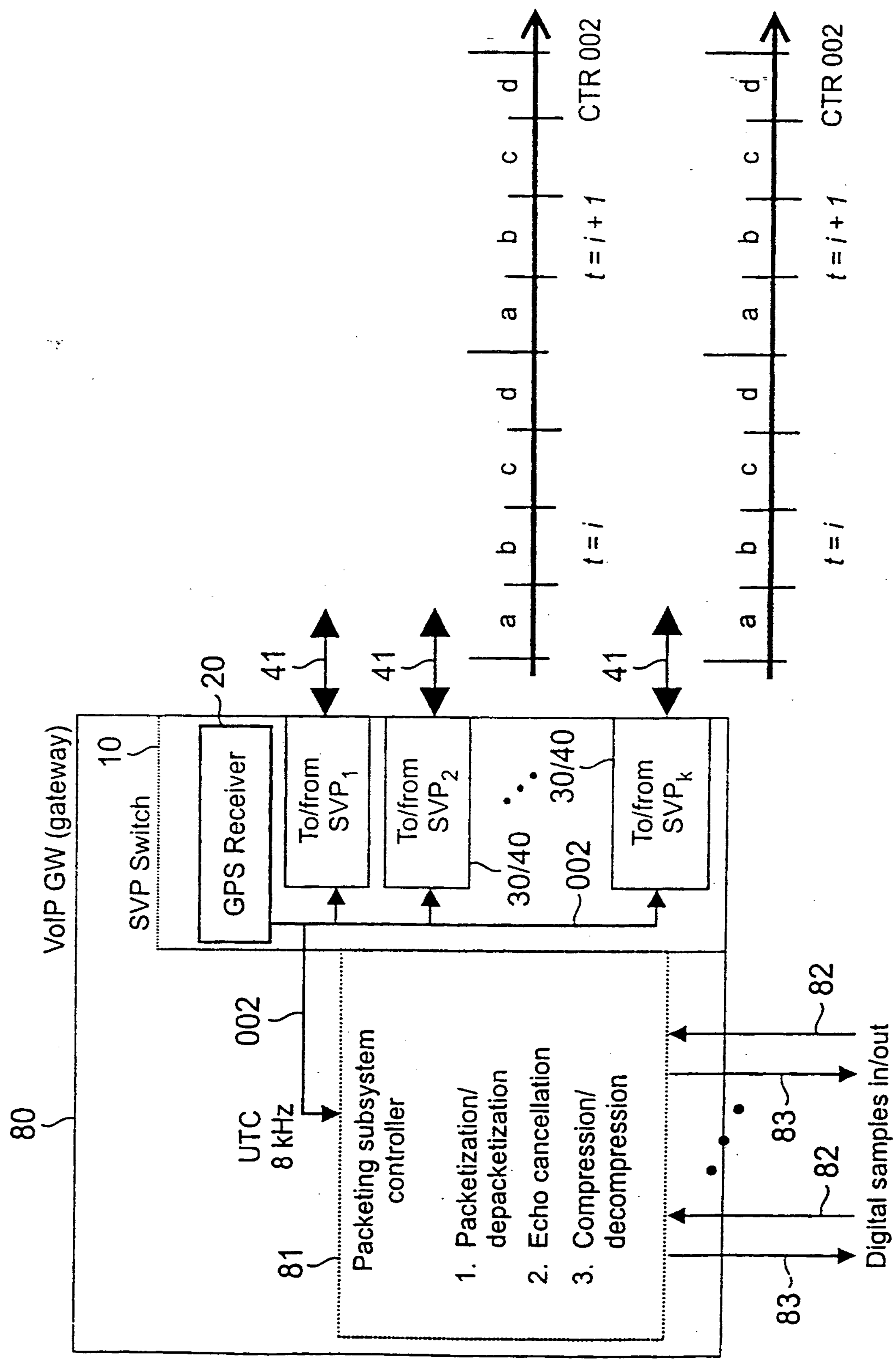

80
VoIP GW (gateway)
10
SVP Switch
20
GPS Receiver
41
To/from SVP1
To/from SVP2
To/from SVPk
30/40
002
UTC 8 kHz
81
Packeting subsystem controller
1. Packetization/ depacketization
2. Echo cancellation
3. Compression/ decompression
82
83
Digital samples in/out
a
b
c
d
t = i
t = i + 1
CTR 002

FIG. 33

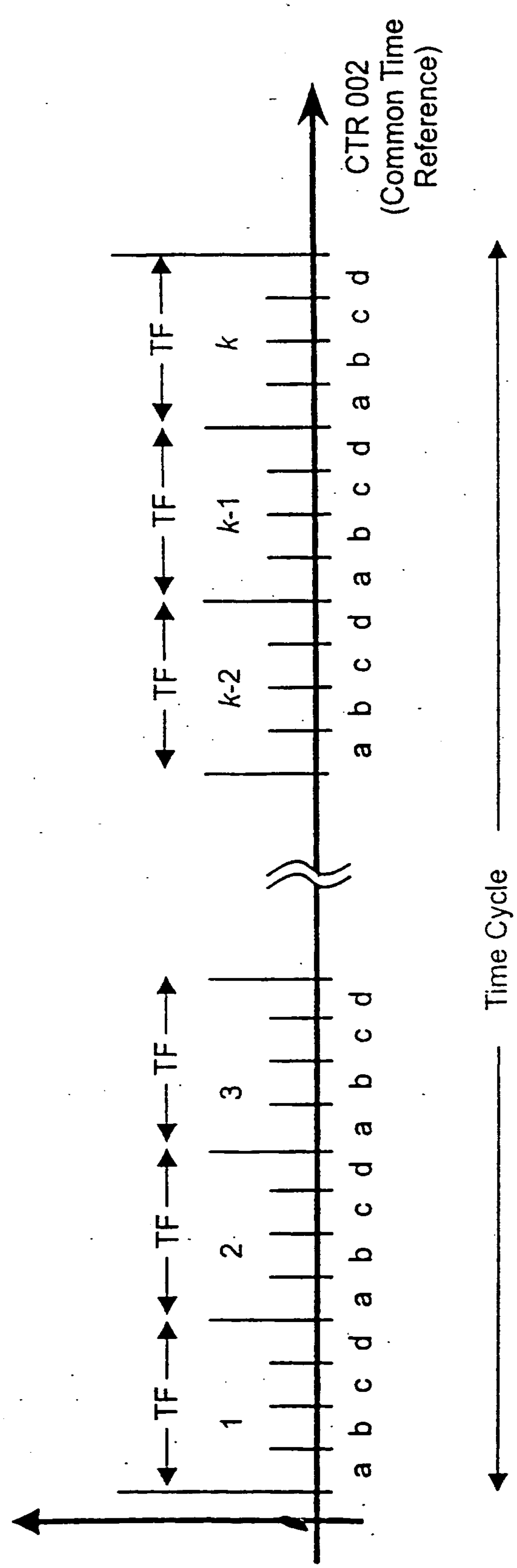

CTR 002
(Common Time
Reference)
TF
TF
TF
TF
TF
TF
1
2
3
k-2
k-1
k
a b c d a b c d a b c d
a b c d a b c d a b c d
Time Cycle

FIG. 34

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/20490

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L12/56 H04Q11/04 H04L12/64

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L H04Q H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JAMALODDIN GOLESTANI S: "A FRAMING STRATEGY FOR CONGESTION MANAGEMENT" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS,US,IEEE INC. NEW YORK, vol. 9, no. 7, 1 September 1991 (1991-09-01), pages 1064-1077, XP000272780 ISSN: 0733-8716 page 1065, column 1, paragraph II -column 2 figures 1,2,4,5,7	1

-/--

[X] Further documents are listed in the continuation of box C.

[ ] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 December 2000	19/12/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lamadie, S

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	LI C -S ET AL: "Pseudo-isochronous cell forwarding" COMPUTER NETWORKS AND ISDN SYSTEMS,NL,NORTH HOLLAND PUBLISHING. AMSTERDAM, vol. 30, no. 24, 14 December 1998 (1998-12-14), pages 2359-2372, XP004150561 ISSN: 0169-7552 abstract page 2360, column 2, paragraph 2.1 page 2362, column 1, line 9 -column 2, line 2 figures 1,2	1
A	LI C -S ET AL: "TIME-DRIVEN PRIORITY FLOW CONTROL FOR REAL-TIME HETEROGENEOUS INTERNETWORKING" PROCEEDINGS OF INFOCOM,US,LOS ALAMITOS, IEEE COMP. SOC. PRESS, vol. CONF. 15, 24 March 1996 (1996-03-24), pages 189-197, XP000622310 ISBN: 0-8186-7293-5 page 190, column 2, paragraph 2.1.1 page 192, column 1, paragraph 2.3 figures 6,7	1

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